DCST
DC SUSTAINABLE TRANSPORTATION

DC Decongestion Pricing Study

Final Report

December 2021

NELSON
NYGAARD

Cover photot from Unsplash by Jeremy Yap

Table of Contents

Page

Executive Summary **1**
Section 1: Introduction **3**
Congestion Pricing 4
Framing the Study 5
Plans Affecting Transportation in DC 7
Section 2. Establishing the Context **9**
Background & History 9
Current Conditions 11
Performance Metrics 12
Transportation-Burdened Areas 28
Future Trends 30
Section 3: Approach and Methodology **31**
Study Area Selection 31
Study Area Descriptions 32
Travel Patterns and Demographics for the Study Areas 33
Screening and Selection of Pricing Tools 37
Selected Pricing Tools and Scenarios 41
Considering Technology for Pricing 45
Tolling Technologies 46
Parking Technologies 49
Implementation Considerations 50
Technology and Infrastructure 50
Tolling, Commuter Taxes, and Home Rule 51
Regulatory and Review Considerations Within DC 51
Additional Implementation Considerations Outside of DC 54
Development and Calibration of Analytic Model 55
Background on the BTA 55
Application of the BTA to DC 56
Section 4: Pricing Scenarios and Results **59**
Main Scenarios: Defined Parameters 59
Main Scenarios: Implementation Costs 63
Main Scenarios: Analysis Results 65
Scenarios 1-5: Measures of Effectiveness 65
Scenarios 1-5: Model Results 67
Scenario 6 73
Refined Scenarios and Results 74
Sensitivity to Varying Price and Charging Times 75
Providing More Benefits to Low-Income Travelers 76
Evaluating Scenarios Against Equity Metrics 78
Section 5: Conclusion and Next Steps **81**
Planning During Uncertain Times 81
Incremental Implementation 83
Further Model Analysis 81
Identification of Revenue Allocation 81
Agency Collaboration and Jurisdictional Coordination 82
Community and Stakeholder Education 82

Appendix A: Review of Parallel Plans 85
moveDC (2014) & moveDC Update (2021) 85
DDOT Bus Priority Network Plan (2019) 85
Comprehensive Plan (2020) 86
Sustainable DC 2.0 (2019) 86
District Mobility (2017) 86
Vision Zero Action Plan (2015) 87
Clean Energy DC (2018) & Progress Report (2020) 87
Health Equity Report (2018) 88
MWCOG Visualize 2045 Plan (2018) 88
WMATA Bus Transformation Project (2019) 89
Appendix B: Balanced Transportation Analyzer 90
Model Vetting 90
Governmental Applications 90
Data Inputs 91

Table of Figures

Page

Figure 1 Mode Share for DC and DC Region (ACS 2018) 4
Figure 2 Expected Impacts of a Congestion Pricing Program on Equity Metrics 6
Figure 3 Demographics of Washington, DC (ACS 2017) 9
Figure 4 DC Residential Sub-Areas (Federal Housing Administration 1937) 10
Figure 5 Timeline of DC's Population Changes (1930-2020) 11
Figure 6 Average Household Commute Time by Mode (ACS 2017) 13
Figure 7 Access to Regional High-Capacity Transit (ACS 2017, Custom LEHD Data, District Mobility) 14
Figure 8 Demographics of Residents within a Half-mile of High-Capacity Transit and All DC Residents (ACS 2017) 15
Figure 9 Average Housing and Transportation Cost Burden as a Percent of Household Income (CNT HTI) 15
Figure 10 Commute Time by Transit (ACS 2017) 16
Figure 11 Commute Time by all modes and Average Household Spending on Transportation (ACS 2017, CNT HTI) 17
Figure 12 Median Household Income in DC (ACS 2017) 18
Figure 13 Displacement of Low-Income Households Across the Region (OpenData DC, ACS 2017, IMO) 20
Figure 14 Characteristics of Areas that Lost or Gained Low-Income Household Populations (ACS 2017) 21
Figure 15 Amount of Driving and Commute Time in DC (OpenData DC, ACS 2017) 22
Figure 16 Demographics of Areas with Longest Commute Times and All DC Residents (ACS 2017) 23
Figure 17 Pedestrian and Bicyclist Fatalities by Ward, 2015-2019 (OpenData DC, Vision Zero Collision Data) 24
Figure 18 Walking and Biking Safety and Fatal Crashes, 2015-2019 (OpenData DC, District Mobility Study, Vision Zero Collision Data) 25
Figure 19 Asthma Prevalence Among Adults in DC (OpenDataDC, ACS 2017, CDC) 27
Figure 20 Demographics of Areas with the Highest Asthma Prevalence and Demographics of all DC Residents (ACS 2017) 28
Figure 21 Transportation-Burdened Residence Areas and Characteristics 28
Figure 22 Transportation-Burdened Residence Areas (OpenDataDC, ACS 2017, IMO) 29
Figure 23 Conceptual Boundaries of the Downtown Study Areas (OpenData DC, moveDC) 32
Figure 24 Income Level by Means of Transportation (CTPP 2012-2016) 34
Figure 25 Means of Transportation by Minority Status (CTPP 2012-2016) 35
Figure 26 Commute Mode Breakdown of Downtown Study Areas (CTPP 2012-2016) 35
Figure 27 Commute Mode Breakdown of Downtown Study Areas 36
Figure 28 Residents of Transportation-Burdened Areas Working in the Small Downtown Study Area (CTPP 2012-2016) 37
Figure 29 Pricing Tools Summary 38
Figure 30 Pricing Tools and Infrastructure (from left, clockwise): Tolling gantry with transponder and license plate camera; Oregon's OreGo RUC program; Truck tolling equipment in Germany 40
Figure 31 Study Area Daily Entries 57

Figure 32 Study Area Daily Entries by Mode 58
Figure 33 Congestion Pricing Scenario Parameters 60
Figure 34 Estimated Capital Expenses, Lifecycle Costs, and Operating Expenses: Scenarios 1-4 64
Figure 35 Model Results from Congestion Pricing Scenarios 1-3 67
Figure 36 Model Results from Congestion Pricing Scenarios 4 and 5 68
Figure 37 Mode Shifts for Scenarios 1-3 (Small Downtown Study Area) 69
Figure 38 Mode Shifts for Scenarios 1-3 (Large Downtown Study Area) 70
Figure 39 Mode Shifts for Scenario 4 71
Figure 40 Societal Net Benefits for Scenario 1.S 72
Figure 41 Societal Net Benefits and Costs 73
Figure 42 Scenario 6: Estimated Decrease in On-Street Parking Demand 74
Figure 43 Refinements to Scenario 1.S to Charged Price, Charging Times, and Charging Days 75
Figure 44 Refinements to Scenario 4 to Charging Time and Price 76
Figure 45 Refinements to Scenario 1.S - Exemptions for Low-Income DC Residents, and Reinvestment of Revenue in Transit 77
Figure 46 Congestion Pricing Scenario Impacts to Equity Metrics 79
Figure 47 Start Public Conversation About Program Goals 83
Figure 48 One Potential Path Forward 83
Figure 49 BTA Data Inputs 91

EXECUTIVE SUMMARY

This report provides a basis for discussion of transportation equity in Washington, DC, while providing guidance on potential congestion pricing tools – one of several ways that transportation equity can be improved in the District and its region. The study analyzes the District's current transportation system with respect to access, affordability, and convenience for residents, workers, and visitors and examines the safety and health implications of this system. An equitable roadway pricing system can mitigate roadway congestion, increase transportation network efficiency, improve air quality, reduce the number of roadway crashes, provide additional revenue for transit, and encourage mode shift.

This report acknowledges that events beginning over 100 years ago led to large-scale racial segregation in the region, which in turn created disparities in commute times and associated health and safety risks for majority Black communities. Immigrant communities – composed of people that have moved to DC to seek refuge from unrest or poverty in other countries – often experience similar access and health issues, as they reside in Black-majority areas in DC and other areas with poor transportation performance.

Through this project's analysis, the study team, the District Department of Transportation (DDOT), and DC Sustainable Transportation (DCST) document that BIPOC (Black, Indigenous, and people of color) communities face greater challenges with transportation access, cost, and safety. With that recognition, the team commits to exploring congestion solutions that will not further burden communities that face greater difficulties in attaining better jobs and quality of life. Congestion pricing can generate revenue that, if reinvested in transit and other sustainable transportation options, can help reduce burdens and increase benefits to those communities.

This study recognizes that the current transportation system does not efficiently allocate access to DC's roadway network – it essentially charges everyone who drives both directly (through the cost of a vehicle) and indirectly (through congestion delays). It also charges people who take transit through fares and delays. In both cases, those with fewer resources bear higher costs, relative to their resources. At the same time, any new system for allocating access will have varied impacts on different types of travelers. A well-designed system can ensure that costs do not increase for those who can least afford them, while providing better service for all. An explicit objective of the system should be to improve the quality of transit and other services to improve access and provide quality choices.

In developing this report, the project team was supported by a steering committee composed of members from DCST, DDOT, DC's Office of Planning (OP), the Office of the Deputy Mayor for Operations and Infrastructure (DMOI), New Urban Mobility Alliance (NUMO), Natural Resources Defense Council, the Federal City Council, Greater Greater Washington, and the Transportation Equity Network. The team assessed the current transportation system, identified inequities, and recommended metrics for evaluating systemic, pricing-based transportation strategies. The team used a specially designed transportation model to assess congestion pricing methods and their effects. The outputs of this model provided an overview of the strengths and weaknesses of various

congestion pricing methods and focused information on their transportation equity benefits.

During the development of this report, the COVID-19 pandemic drastically changed short term conditions of DC's transportation system. Public health, service for essential workers, and additional accommodations for pedestrians and bicyclists became top priorities. Transit ridership declined significantly during the pandemic, but bus ridership retained a significantly higher level of ridership than did rail. In the first two months after the region's Stay at Home orders were issued in March 2020, Washington Metropolitan Area Transit Authority (WMATA)'s Metrobus ridership declined by 78% while Metrorail ridership declined by 93%. As of October, Metrorail ridership remained very low (84% less than in 2019) while Metrobus ridership had rebounded somewhat (52% less than in 2019)[1]. This highlights two inequities in current transportation service: more essential workers ride the bus than rail, and those same essential workers may not have a car or other way to get to work. Census data indicates that very few low-income earning workers commute to downtown DC by automobile, while WMATA ridership data points to stronger dependence on the bus network than rail. The bus system is a critical means of access to local services and essential jobs. Because buses share roadways with private automobiles and other vehicles, bus transit service is impacted by roadway congestion. By reducing this congestion, congestion pricing can help create a more equitable transportation system.

The COVID-19 pandemic contributed to the delayed delivery of this report, originally due to the DC Council in July of 2020.When Stay at Home orders were issued across the DC metropolitan area, progress on the study became gradual. The project's team and engaged members of the steering committee needed time to recreate their office spaces at home and to normalize meetings across international time zones.

Undertaking this study during the COVID-19 pandemic only elevated the importance of finding tools to rebalance the benefits and burdens of the District's transportation systems. The pandemic brought to light the extent to which lower-income residents of the District are disproportionately burdened by congestion and realize fewer of the system's benefits. So, although the pandemic has contributed to the report's delayed delivery, it has also provided the study team key information that contextualizes the challenge and reinforces the importance of addressing congestion to achieve a more equitable transportation system.

Although the long-term effects of the pandemic on transportation remain uncertain, this report highlights congestion pricing scenarios that merit further study for potential implementation in DC or the region, particularly as vehicle traffic levels begin to approach pre-COVID levels. As traffic volumes return to near pre-pandemic levels, restoring trust in the safety of public transit is imperative to curbing congestion in the short term. In the long term, congestion pricing can help generate revenue for transit improvements and encourage mode shifts so that DC can definitively cut congestion and become a more sustainable and resilient city.

Section 1: Introduction

In 2019, Mayor Bowser and the Council of the District of Columbia (DC Council) commissioned the first study of how transportation pricing (also known as congestion, decongestion, or road pricing) could help achieve key civic priorities, chiefly promoting equity in transportation access and impacts, increasing system efficiency, reducing pollution, and generating revenue for sustainable transportation. The District Department of Transportation (DDOT) granted funding to DC Sustainable Transportation (DCST) – a coalition of advocacy, business, and government entities – to work with a consultant team to complete the study. In scoping the study, DCST specified a focus on how the current system serves disadvantaged communities and travelers in DC, and in turn how decongestion pricing tools might bring about better outcomes for the people who see the fewest benefits, often at the highest costs, from the current transportation system.

Understanding how the city and region work today requires consideration of interrelated influences, namely: DC's place in the region; the city and region's history with race, segregation, and integration; and the relationship between where people live, work, and how they travel.

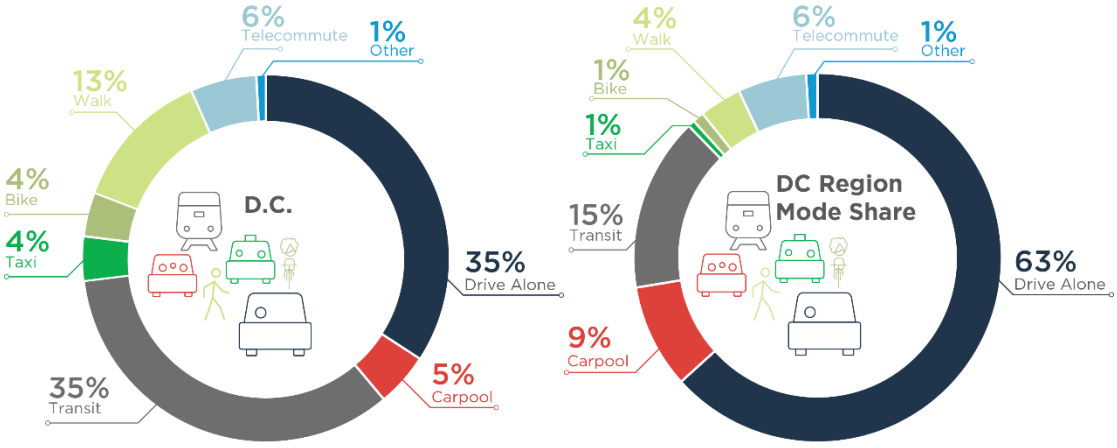
While the past decade has seen DC invest in walking, biking, and transit service, the legacy of sixty years of prioritizing private automobile travel shows on DC's streets. This has translated into the designation of one-way streets, removal of on-street parking and/or imposition of rush hour parking restrictions, accommodation of higher travel speeds, and design that discourages people from walking or riding bicycles. These measures benefit people who drive, to the detriment of people who do not or cannot drive while putting them in harm's way when they walk, bike, or access transit.

The region's major transit provider, Washington Metropolitan Area Transit Authority (WMATA), attracts the second-highest rail ridership in the country after New York City, but it did not have a dedicated fund until 2018 when DC, Maryland, and Virginia all committed to the establishment of a dedicated funding stream for WMATA. Before 2018, funding varied annually and was subject to the financial pressures of local jurisdictions in the WMATA service area, leading to years of deferred maintenance. However, the new dedicated funding is limited by spending caps, still falls short of capital and operating needs, and is subject to appropriation from each jurisdiction.

In recent years, the DC government has begun to rebalance the transportation system and increase the safety and ease of multimodal travel. However, the legacy of auto-oriented planning is still visible in the abundance of space allocated to vehicle travel and storage (parking), compared to the minimal allocation of dedicated space for mass transit or active transportation. This approach has benefited car owners, as commuting by private motor vehicle offers the shortest commute times for residents across much of DC; however, this form of travel has caused the DC region to rank third nationally in congestion-related delays,[2] causing adverse effects including unreliable travel times, lost productivity, and most notably, lost economic gains.[3]

According to the Census' American Community Survey (ACS) data from 2018,[a] over 50% of DC residents' commute trips were by walking, biking, and transit, a much higher share than for residents across the region (Figure 1). Across the DC region, 63% of all workers drove to work, while only 34% of DC residents did the same. Given that disparity, DC cannot afford to continue to prioritize the region's vehicle use to the detriment of their residents' travel experience and health outcomes.

Figure 1 Mode Share for DC and DC Region (ACS 2018)



CONGESTION PRICING

Congestion pricing recognizes that congestion on our streets and highways results primarily because providing access "for free" leads people to overuse the system. Although drivers do pay to drive, their costs – which include a vehicle, insurance, gas, maintenance, and parking – are relatively fixed. Therefore, drivers generally do not perceive a monetary cost of individual trips, aside from the perceived cost of driving time and any delays caused by congestion. The economic principle of supply and demand makes clear that reducing congestion requires drivers pay a price that matches overall demand to the supply of roadway space available.

By applying a cost to using the roadway at congested times and locations, localities can encourage travelers to reconsider their transportation choices. A small reduction in the number of vehicles on a congested road can translate to a substantial reduction in congestion. As one mode of transportation becomes more expensive, alternative transportation options can become more attractive. For example, increasing prices on a tolled road during rush hour can motivate travelers to take transit, carpool, shift travel times, use a different route, or eliminate the trip altogether. A traveler's choice depends on their value of time, budget, availability of alternatives, and other preferences. Congestion pricing can help reduce vehicular congestion on roadways and can also be used to encourage mode shift from private vehicles to less land-intensive and polluting modes of transportation. Increasing commuting trips to modes such as transit, walking,

[a] All data for this study collected in late 2019 with data sets ranging from 2012-2019. Thus, discussions in this study reflect long-term trends that were present prior to the COVID-19 pandemic.

and biking will help DC achieve their transportation targets identified within the Sustainable DC 2.0 plan. Proven secondary benefits to congestion reduction are reduced traffic crashes[4] and reduced asthma-related hospital visits[5].

FRAMING THE STUDY

The project team worked with DCST and the steering committee to articulate a vision for the transportation system, drawing on relevant existing congestion pricing work. This vision guided the study analysis, pricing design, pricing scenario details, and results.

Study Vision: DC strives to create a transportation system that provides safe, convenient, and affordable access to a full range of transportation choices, for residents, workers, and visitors, with explicit consideration of their race, age, ability, income, and location within DC.

To support this vision, the study team identified key metrics that would focus the equity analysis and subsequent review of how proposed pricing scenarios would affect those indicators. The metrics related to transportation and equity in DC:

- **Affordability:** Transportation costs as a percent of income compares the availability of transportation options across geographic and demographic groups.
- **Access:** The transportation mode that a household chooses to use is largely dependent on the convenience or access to that mode. Proximity to Metro or other high-capacity or high-quality transit influences whether a person chooses that mode.
- **Efficiency:** Time spent commuting by various transportation modes can play a large part in determining a household's mode of choice.
- **Health and Safety:** The level of vehicle traffic, number of traffic collisions, air quality, and quality of the walking and bicycling environment are all factors that contribute to a person's health and safety. Additionally, these factors also can affect household mode choice. Congestion pricing programs impact travelers differently, depending on their mode of travel. Figure 2 summarizes the expected impacts to travelers of each mode according to these equity metrics.

Figure 2 Expected Impacts of a Congestion Pricing Program on Equity Metrics

Equity Metric Travel Mode	Access & Affordability	Efficiency	Health & Safety
Driving	Access would be limited during priced times to drivers willing to pay; however, low-income exemptions could mitigate this issue.	Drivers willing to pay the charge would experience shorter commutes (i.e. greater efficiency) within the charged area.	Decreased vehicle use and reduced congestion could improve air quality Faster automobile speeds may increase collisions or serious crashes unless additional road improvements are coupled with congestion pricing program.
Trucks	Some truck trips (shipments) may be delayed, as trucks may adjust delivery times to avoid congestion fees. Due to charged fee, delivery trucks may pass the charge onto customers, resulting in increased price in goods.	Truck trips willing to pay the charge to enter and/or drive within the charged area could be shorter (more efficient) with less congestion.	Reduction in overall number and congestion of truck trips during peak hours could improve air quality both within and outside of charged zone. Truck trips may be reduced during peak/charged hours and/or shift to alternative delivery vehicles, including e-bikes.
For Hire Vehicles *(FHVs)*	Trip fares within the charged zone may increase due to congestion pricing charges, excluding riders that cannot afford increase costs from this service.	FHV trips can be made in a timelier manner due to less congestion.	Varied impacts, dependent on the congestion pricing program
Metrorail	Transit investment from congestion pricing revenue could fund new rail stations or rail expansion projects, putting more regional residents within a ½ mile from high-capacity transit. Transit investment from congestion pricing revenue could also offer fare reductions for low-income riders.	Transit investment from congestion pricing revenue could reduce train headways, increase service, and improve reliability on Metrorail.	Decreased vehicle trips could improve air quality. Additionally, transit investment from congestion pricing revenue could fund bus electrification initiatives, which could also improve air quality. Increased transit ridership could improve individual health through promoting walking to/from transit stop.
Metrobus & Circulator	Access could be improved with transit investments from congestion pricing revenue.	Buses would experience less congestion on roadways in charged area, shortening commute times and increasing reliability.	
Commuter Bus & Rail	Commuter buses would have faster travel times due to decreased congestion. No impacts to commuter rail are expected unless this mode is targeted for reinvestment or improvements (paid by revenue from congestion pricing program).		
Micro-Mobility Modes *(Walking, Bicycling, and other emerging mobility)*	Investments to pedestrian and bicycle safety and infrastructure (paid for through congestion pricing revenue) could increase regional access to safe accommodations, increasing ridership.		Increased walking trips and biking trips could promote better health and activity levels during commute. Congestion pricing revenue could help fund safety improvements to pedestrian and bicycle infrastructure.

PLANS AFFECTING TRANSPORTATION IN DC

A number of recent plans, studies, and reports offer insights into how the DC transportation system could become more successful and sustainable. Many of these plans are already being implemented and will drive local and regional improvements in equity, climate, transportation, and health. Several of these plans and studies, described below, were reviewed to frame this project's vision and goals. A more extensive summary of these reports can be found in Appendix A.

- **moveDC (2014) & moveDC Update (2021):** moveDC, completed in 2014, laid out a progressive strategy for a sustainable transportation system, which included a congestion charging zone for the downtown area and tolled express lanes at major entry points to the District. The moveDC update will be completed in 2021 and aims to apply an equity framework to transportation decision-making and investments in the District.
- **DDOT Bus Priority Network Plan (2021):** More District residents ride the bus each day than Metrorail. However, over the last decade, average bus speeds have declined. To enhance bus service District wide, DDOT is working to improve bus travel speeds and reliability through a series of bus priority projects and programs. The Bus Priority Program will assist DDOT in identifying bus priority corridors and enable the development of a toolbox of improvements, like bus lanes, to help improve bus speeds and reliability.
- **Comprehensive Plan (2020):** The vision for a more equitable DC is primarily expressed through its Comprehensive Plan. The Comprehensive Plan update was approved by DC Council in May 2021; the plan has significantly strengthened how it addresses dimensions of equity. It also includes a specific Transportation Element that describes the role of the transportation system in promoting DC's vision and values.
- **Sustainable DC 2.0 (2019):** The original Sustainable DC plan was released in early 2013. The plan, and subsequent updates, have provided a framework for more detailed individual plans undertaken by the District to address equity, climate, transportation, and health. Sustainable DC 2.0 identifies DC as a leader of traffic congestion in the nation and its transportation emissions as the second highest source of greenhouse gas in the city. One of the plan's 20 transportation-related recommendations calls for a study to outline equitable congestion reduction strategies for DC.
- **District Mobility (2017):** The District Mobility tool and study provide measures of congestion, reliability, and accessibility. It includes data at the Ward and neighborhood level for all modes, offering valuable insight into inequities in system performance – for example, that bus congestion is worse in lower-income neighborhoods.
- **Vision Zero Action Plan (2015):** The Vision Zero Action Plan aims to achieve zero fatalities and serious injuries on DC streets by 2024 through more effective use of data, education, enforcement, and engineering.

- **Clean Energy DC (2018) & Progress Report (2020):** Clean Energy DC is DC's climate and energy plan. It explains how the District will use forward-looking energy policies to achieve its greenhouse gas (GHG) emissions targets, 50% below 2006 levels by 2032 and carbon neutrality by 2050, while also encouraging innovation, efficiency, and resiliency. Climate Energy DC specifically sought to account for the disproportionate climate change impacts on frontline communities by considering social and economic indicators - including poverty, health indicators, and age - as part of its vulnerability analysis.

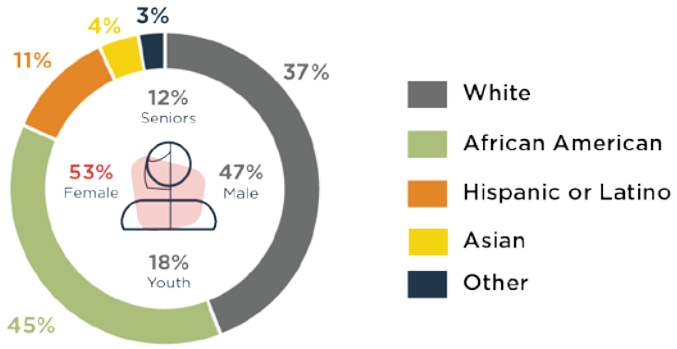
The Clean Energy DC plan found that Wards 7 and 8 are most vulnerable to climate change given high levels of unemployment, poverty, obesity, asthma, and the large number of elderly people. The plan also found that Ward 7 is also home to the largest number of vulnerable community resources, including schools, medical services, and public housing that sit along the flood-prone Watts Branch tributary.

- **Health Equity Report (2018):** The plan provides a baseline assessment of health equity issues and opportunities in Washington DC. Using a social and structural determinants of health approach, data on the leading causes of death and projected life expectancy at birth was paired with social and economic data and geographic information systems (GIS) tools to develop a snapshot of differential health outcomes across the city.
- **MWCOG Visualize 2045 Plan (2018):** Visualize 2045 is the federally required long-range transportation plan for the National Capital Region. It identifies all regionally significant transportation investments planned through 2045 and provides detailed analysis to help decision makers and the public "visualize" the region's future under current plans. The plan identified a set of aspirational initiatives for the region; those initiatives, which encompass resolving some of the region's biggest transportation challenges, are listed in Appendix A. In summer 2020, the Transportation Planning Board (TPB) adopted an equity statement, affirming that the board would take equity into account when making policy decisions or setting work activities.
- **WMATA Bus Transformation Project (2019):** The Project sets out an ambitious future strategy and details 26 recommendations with proposed schedules, case studies, and status updates. WMATA has outlined three objectives to achieve the goal of creating a bus system that is affordable and equitable: 1) Ensure equitable transit service for those who most depend on it (e.g., low-income, seniors, youth, individuals with no vehicle); 2) Provide riders with affordable end-to-end transportation; and 3) Enhance mobility options for people with disabilities.

SECTION 2. ESTABLISHING THE CONTEXT

BACKGROUND & HISTORY

Figure 3 Demographics of Washington, DC (ACS 2017)



The District of Columbia and broader DC Metropolitan Area are among the most racially and ethnically diverse cities and regions in the United States.[6] A plurality of DC residents are Black, and the non-white population comprises 63% of all residents (Figure 3).[7] Although DC as a whole is diverse, the racial demographics vary significantly throughout its eight wards. DC's northeast and southeast areas have much higher Black populations: African Americans in Wards 5, 7, and 8 make up 84% of total residents. Wards 2 and 3, which contain the northwestern and westernmost portions of DC, are 70% white.[8,9,10]

Regionally, within DC and the surrounding ten counties and five cities,[11] the Black population comprises over a quarter of the total, but almost two-thirds live in Prince George's County, Maryland, which is located on the east side of the region adjacent to the Northeast and Southeast quadrants of DC. The county is home to a Black community that is economically diverse. During the 1980s and 1990s, the Black middle class migrated to Prince George's County for a better quality of life. Other Black residents moved there beginning in the early 2000s, because of the rising cost of housing in DC. Currently, Prince George's County is one of the richest majority-Black counties in the country.[12] Despite the Black majority, within the county segregation exists: the northern portion is mostly white and Hispanic/Latinx, while the southern portion is mostly Black.

Segregation in DC and the region is a result of policies in the early to mid 20th century – like protective covenants and redlining (historical redlining map of DC shown in Figure 4) – that kept Black people out of then-white communities, raising economic barriers to more diverse neighborhoods that persist to this day. Across the country, single family zoning invariably makes up the largest category of residentially zoned land (by area) in almost every community. These exclusionary zones often have the "best" schools, the lowest crime rates, and the least diversity. This is true in DC as well. The District of Columbia experienced a large out-migration between the 1950s and 2000, losing almost 300,000 residents. Some people, regardless of race, willingly relocated seeking upward economic mobility and educational opportunities. Some people, mostly white, moved out of DC as the Black population grew, and institutionalized racism and other systemic forces provided white people with more choices. Some people, mostly Black, were

forced to relocate in the name of urban renewal or economic development. This period was followed by a large in-migration from 2000 to present, which includes some movement from the suburbs back into DC, from mostly white people migrating to DC in search of livable, walkable communities and job opportunities. See Figure 5 for a timeline of DC's population changes through the last century.

Figure 4 DC Residential Sub-Areas (Federal Housing Administration 1937)

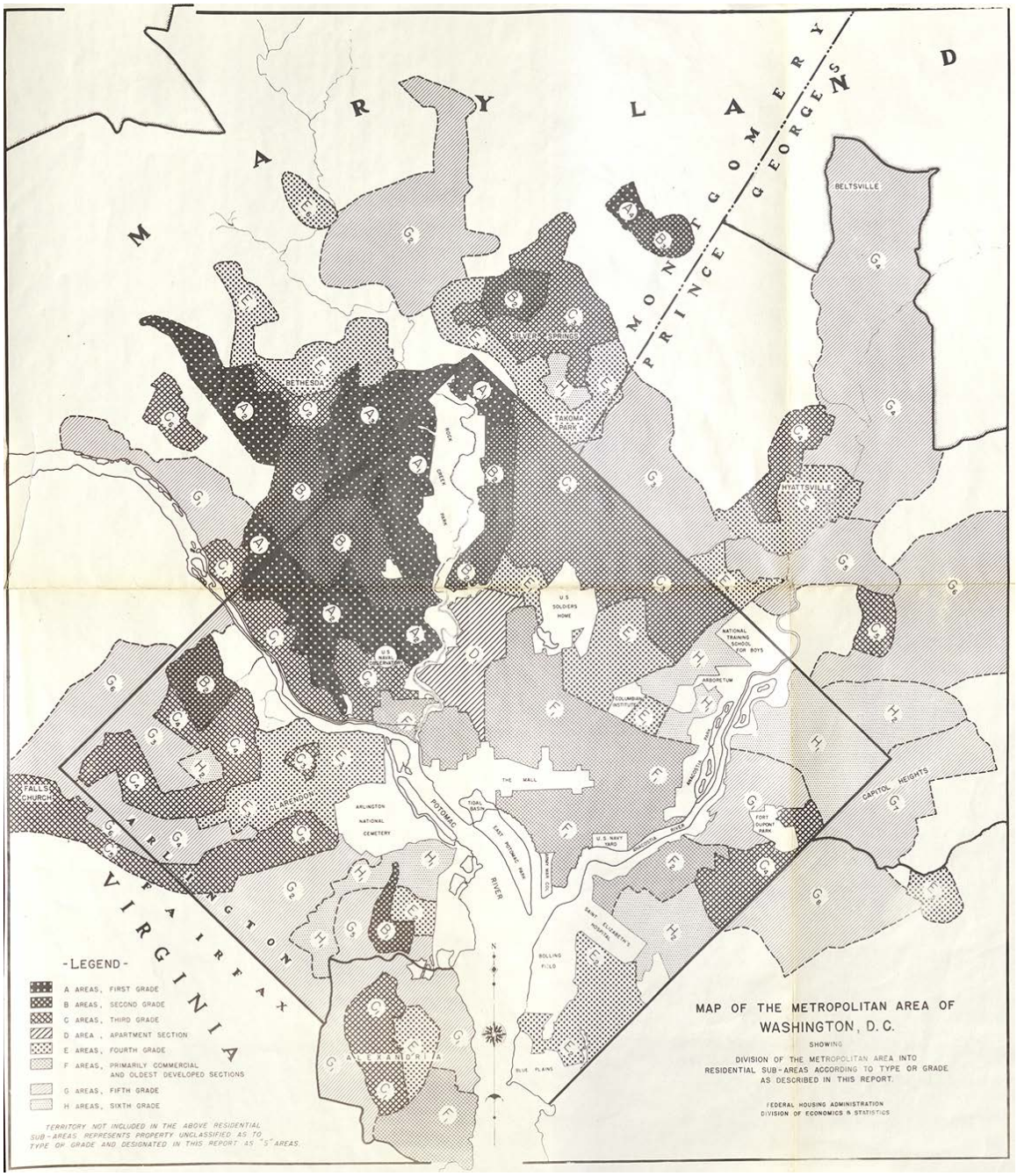
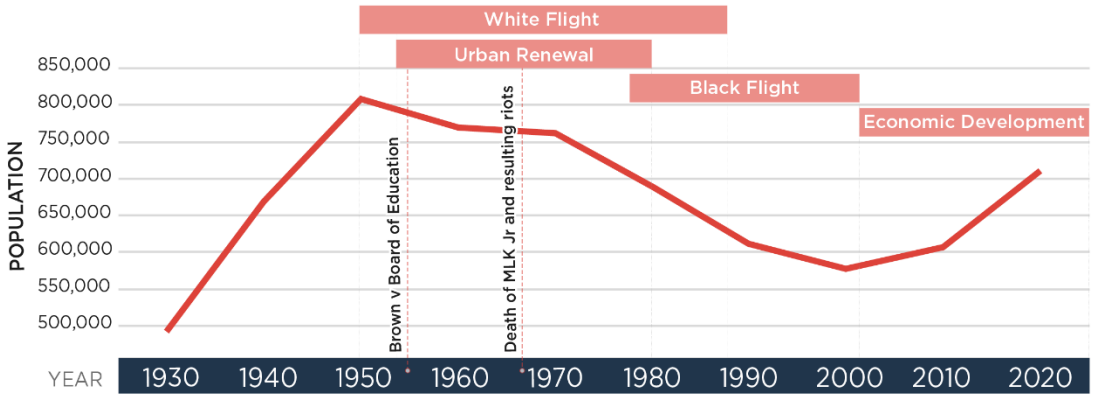


Figure 5 Timeline of DC's Population Changes (1930-2020)



With the influx of new residents into DC, there was another out-migration of mostly Black residents, as rapid growth in housing demand outpaced growth in supply. The result was, and continues to be, market pressure to increase prices, leaving some people unable to afford to purchase a home or pay rental prices. Many lower-income residents, mostly Black and Latinx, began leaving DC for Maryland where rent and housing prices were and continue to be significantly more affordable. Displacement of low-income residents is further explored later in this report.

The next section highlights how many areas facing transportation inequities are predominantly Black. Reviewing the history as to why Black populations are concentrated in these areas provides insight into how DC can resolve entrenched inequities.

CURRENT CONDITIONS

Racial segregation in DC and the region is only one influence among many that have shaped where people live. While DC is a unique city, it exists in a nation that for the last hundred years has been organizing its communities to make car travel the overwhelmingly preferable and practical choice. Other choices, when they exist, are often inconvenient, crowded, expensive (in time, cost, or both), unsafe, or unreliable. While supporters of the automobile-centered system tout its freedom and desirability, it has not proven to be a formula for access for all, but rather for those that can afford it. Even when transit is available, its performance often depends upon jurisdictions' operations and investments, resulting in unequal quality and access across the region.

Downtown DC remains a major job center, but the region's other major centers are largely in Montgomery County, Maryland, and Northern Virginia. This spatial mismatch drives inequitable transportation access in DC and the region, where the east side of DC and its region generally suffer disproportionate negative impacts. Specifically, areas east of the Anacostia River in DC lack efficient transit access to regional jobs and opportunities, which disadvantages primarily Black and Latinx residents. For example, a twenty-mile commute by VRE (Virginia Railway Express) commuter rail from Woodbridge, Virginia, to Union Station in DC takes the same time as riding a bus six miles from Ward 7 to downtown DC during rush hour.

Washington Metropolitan Area Transit Authority operates Metrorail and a Metrobus system. The Metrobus system serves DC and all inner suburban jurisdictions. Given Metrorail's focus on longer transit trips and inter-jurisdictional commutes, some cities and counties have supplemented bus service. The result has been further disparities in investment in transit, as wealthier counties fund more service (like Montgomery County's RideOn and Arlington County's ART), while other areas with fewer resources, such as Prince George's County with TheBus, fund less service. Lacking choices, residents in Prince George's County are thus more likely to drive, creating unnecessary congestion and pollution in Maryland as well as in communities east of the Anacostia River in DC as commuters drive into and through DC. The historic practice of trying to alleviate congestion by widening roads results in unsafe streets leading into and through majority Black areas of DC.

Performance Metrics

Using the four metrics described in Section 1 as a guide, the project team set out to answer fundamental questions about how people's access to jobs, services, and other needs are affected by their transportation system.

- How well does DC's transportation system facilitate affordable and convenient access to the region's jobs, services, shopping, health care and other daily needs?
- Access: Are there systemic disparities in the access to transit and these locations?
- Affordability: Are all transportation choices priced equitably across the region and the systems?
- Efficiency: Are there systemic disparities in the travel time by different modes and between locations?
- Health & Safety: Does efficiency for certain groups put other groups at a disadvantage?

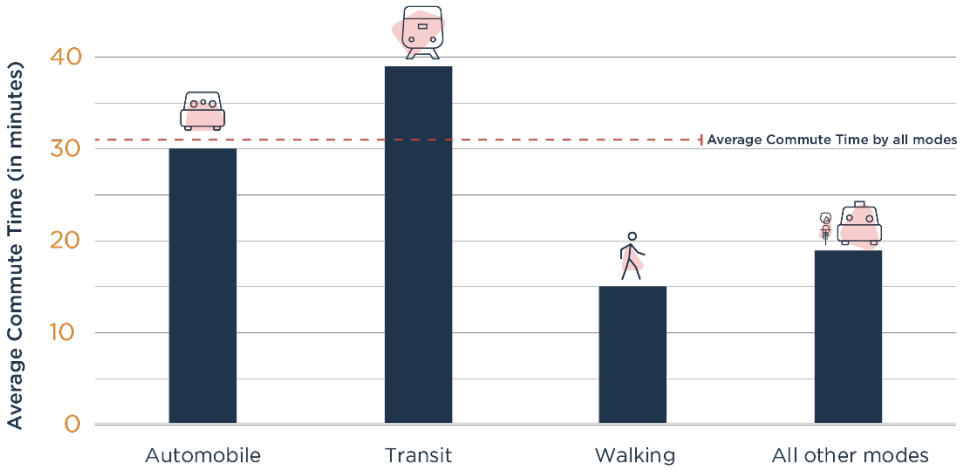
By testing congestion pricing scenarios, the team then attempted to answer a final question: can congestion pricing help reduce or eliminate disparities in the transportation system's efficiency, access, affordability, and health and safety implications. If so, by what means?

The metrics that were identified as indicators of transportation equity are inherently intertwined, as access is often driven by affordability, and efficiency is a result of access.

Access

WMATA's Metrorail attracts the second-highest levels of ridership in the country, however access to – and efficiency of – the system is highly varied across the region. With an average 39 minutes, commute time by transit is the longest of any mode of travel for households in DC (Figure 6).

Figure 6 Average Household Commute Time by Mode (ACS 2017)



Access to Regional High-Capacity Transit

Across the region, people living within a short walk of high-capacity transit stations have higher average household incomes. High-capacity transit is defined here as Metrorail, DC Streetcar, and commuter rail (MARC and VRE). While residents of Maryland and Virginia who live near stations served by high-capacity transit may have higher commute times than DC residents with similar access, they have shorter commute times than DC residents living in neighborhoods farther from high-capacity transit stops. This means that commuting into downtown DC is quicker for some residents of Maryland and Virginia than it is for some DC residents. Figure 7 shows areas within a half-mile of high-capacity transit, and the demographic breakdown of residents within those shaded areas is displayed in Figure 8 Demographics of Residents within a Half-mile of High-Capacity Transit and All DC Residents (ACS 2017).

Figure 7 Access to Regional High-Capacity Transit (ACS 2017, Custom LEHD Data, District Mobility)

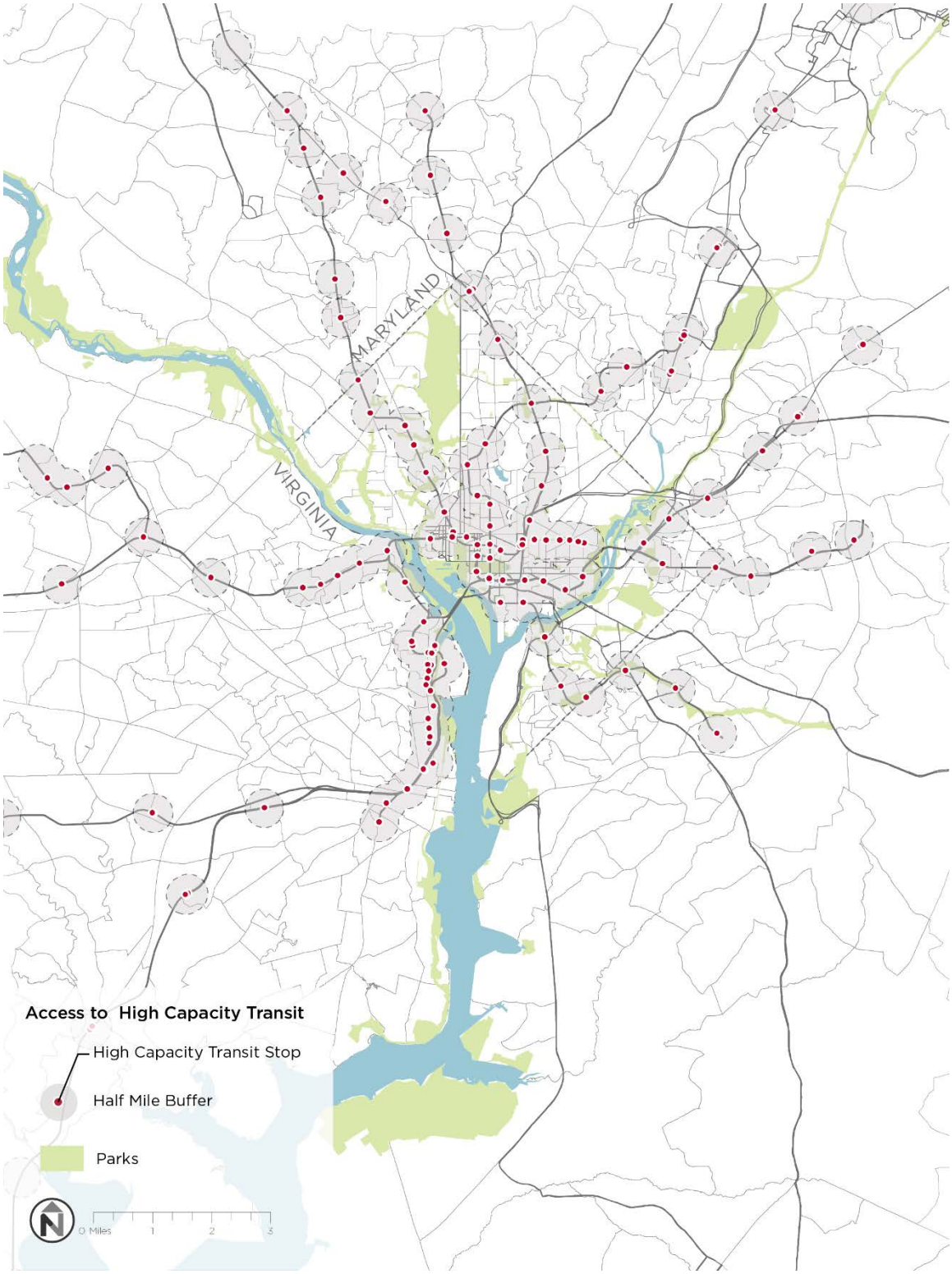
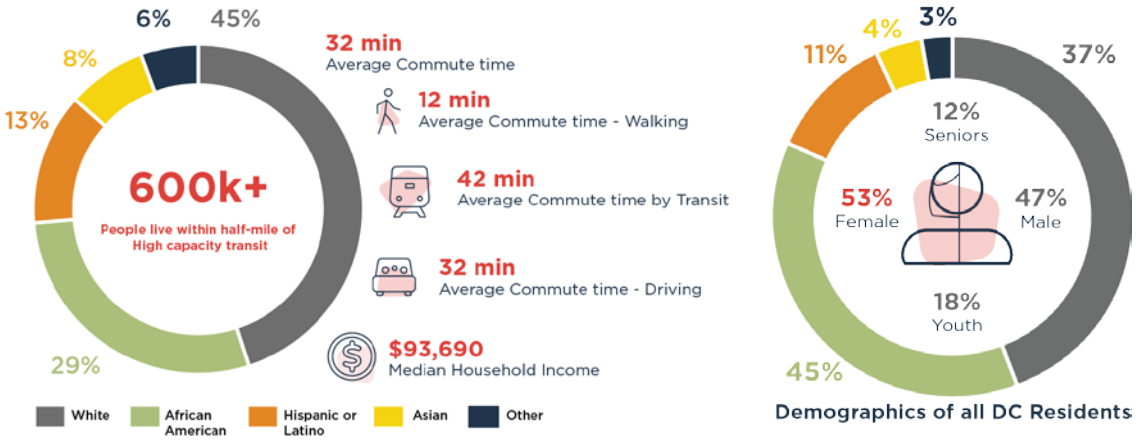


Figure 8 Demographics of Residents within a Half-mile of High-Capacity Transit and All DC Residents (ACS 2017)



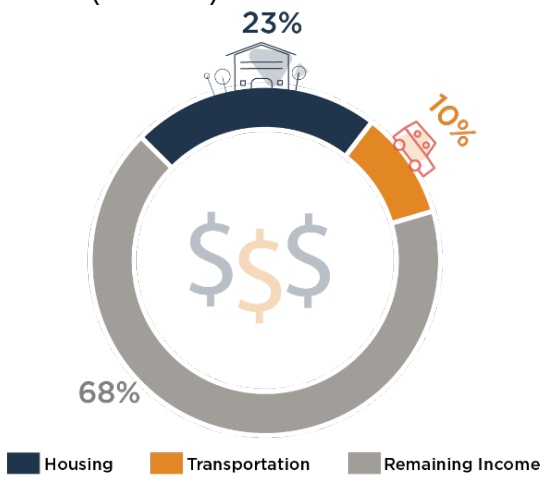
Access & Affordability

Commute Time and Spending on Transportation

Neighborhoods close to both DC's core and the high-capacity transit system have the best multimodal access and shortest transit commute times, as shown in Figure 10.

Areas closest to DC's core also have the shortest commute times by all modes (Figure 11) and typically spend 5% to 9% of their incomes on transportation, lower than the 10% average citywide (Figure 9). In areas outside of DC's central core, households spend more money on transportation (anywhere from 9%-16% of total household income).

Figure 9 Average Housing and Transportation Cost Burden as a Percent of Household Income (CNT HTI[13])



Within DC, the average commute time (regardless of travel mode) is longest for households in upper Northwest, upper Northeast, and east of the Anacostia River. Upper Northeast and east of the Anacostia River are also where median household income is the lowest (Figure 12). These residents face a combined burden, spending more on transportation for poorer service and retaining less income for other expenses including housing, food, and education.

Figure 10 Commute Time by Transit (ACS 2017)

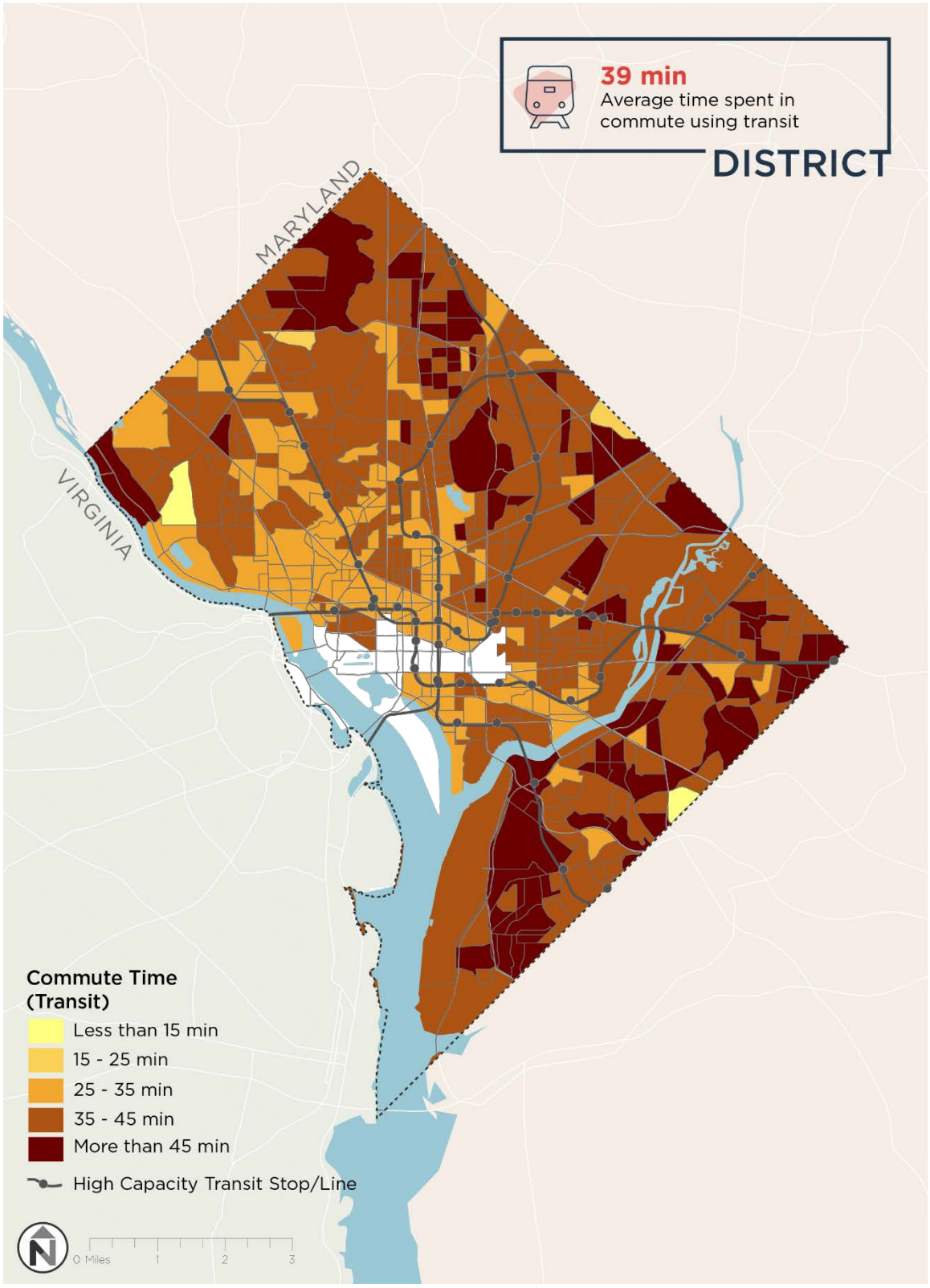


Figure 11 Commute Time by all modes and Average Household Spending on Transportation (ACS 2017, CNT HTI)

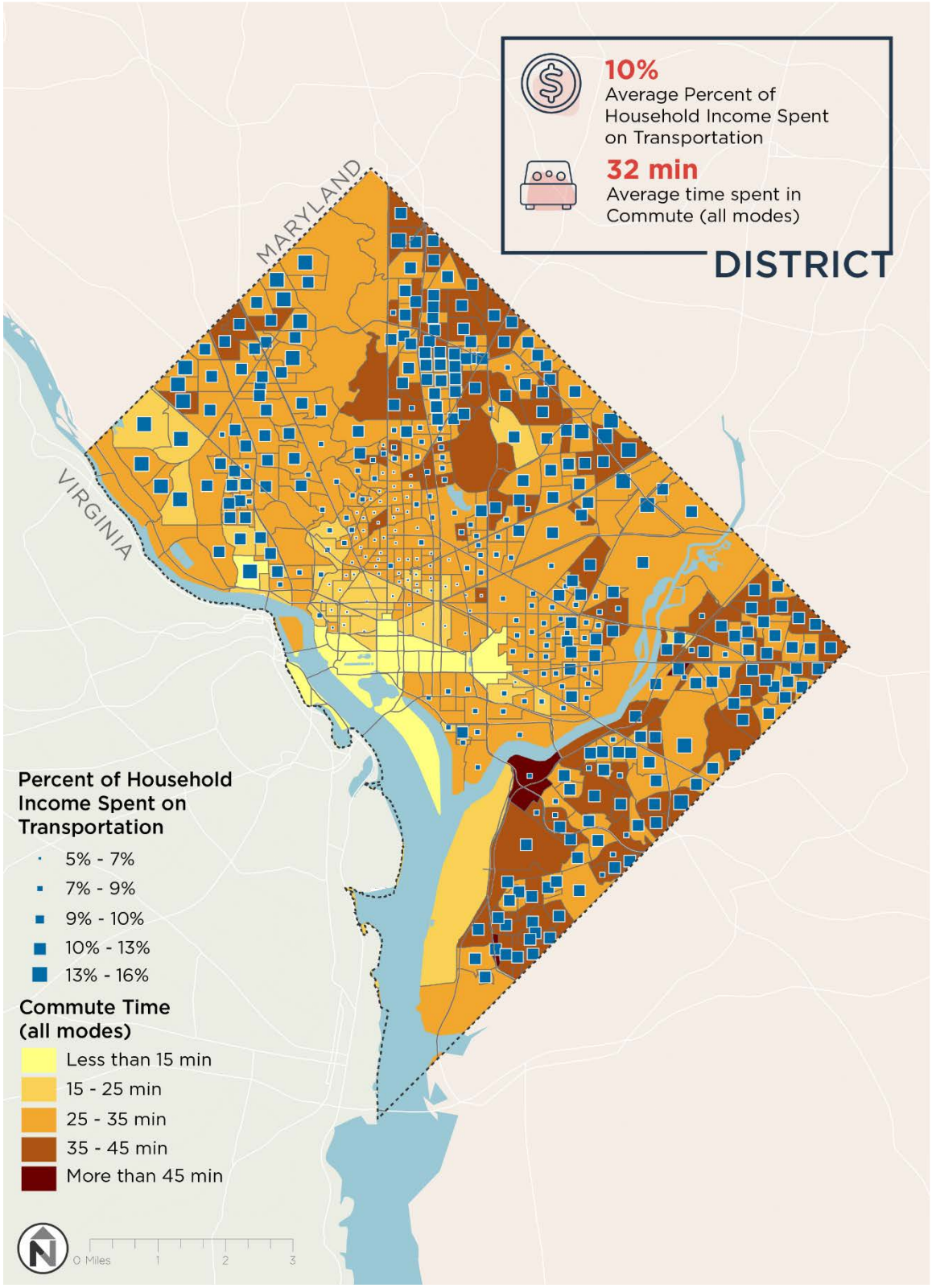
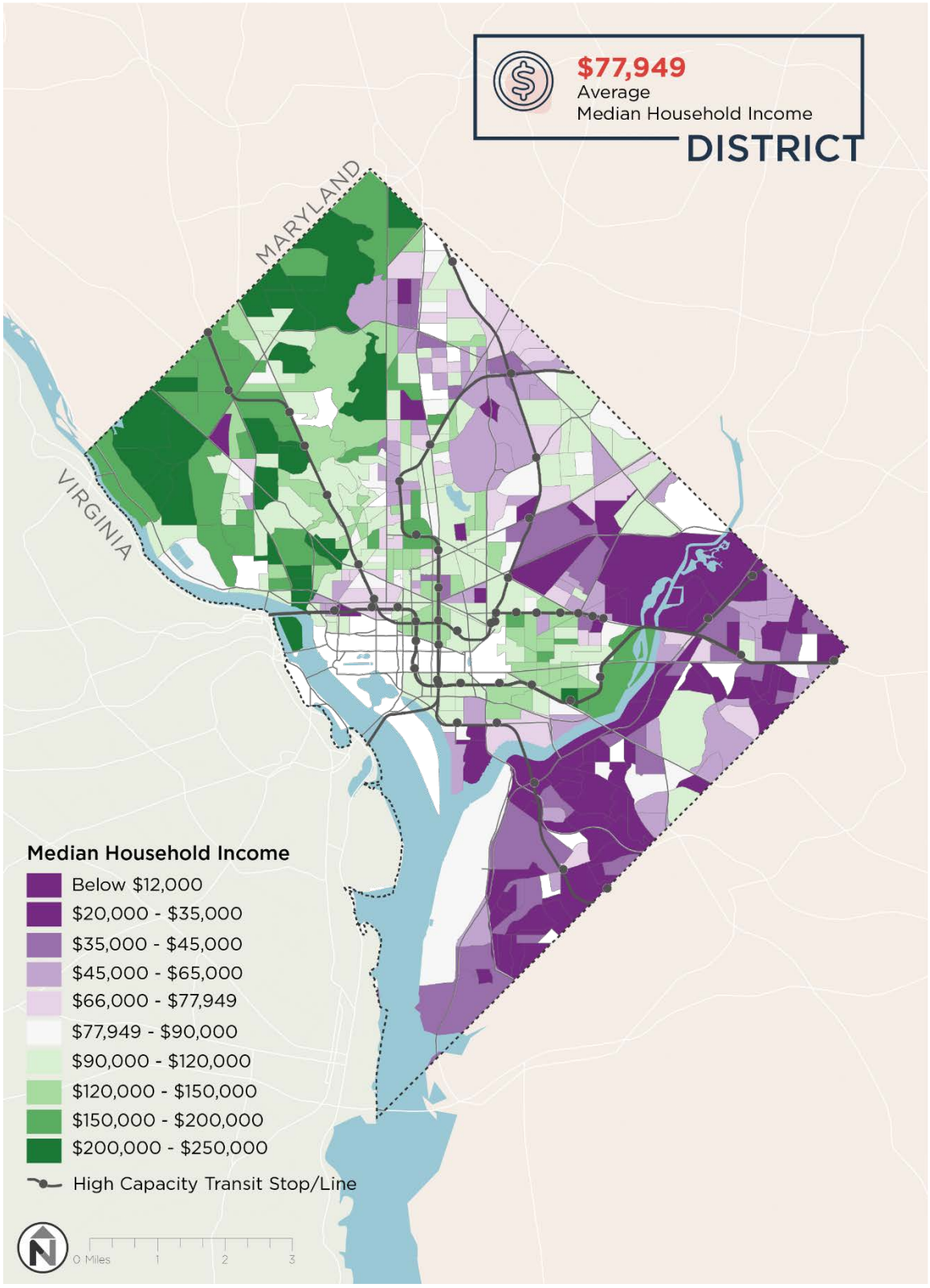


Figure 12 Median Household Income in DC (ACS 2017)



Affordability

Housing, Displacement, and Transportation Consequences

Increasing housing prices in neighborhoods close to downtown DC continue to drive displacement of low-income households to areas farther from the core of the city. According to an analysis on neighborhood economic expansion and decline from the Institute on Metropolitan Opportunity at the University of Minnesota Law School (IMO),[14] between 2000 and 2016 in the DC region, the number of low-income households decreased in areas more centrally located to transit and increased in areas with longer commute times (Figure 13). Within DC, average driving commute times were equal between neighborhoods that lost and gained low-income households, however transit and other mode commute times were longer for those same areas.

The number of low-income households has disproportionally increased in Prince George's County, Maryland. Regionally, the areas to which people have been displaced have higher minority populations overall (higher Black and Latinx populations). Vehicle-owning households in these areas drive close to 15% more (1,500 miles annually) and spend a larger share of their income on transportation, compared to areas where the number of low-income households declined (Figure 14).[15] This data makes clear that DC residents face a financial tradeoff between housing and transportation costs. Cheaper housing typically incurs higher transportation costs, either through longer commute times or the financial cost of vehicle ownership.

Figure 13 Displacement of Low-Income Households Across the Region (OpenData DC, ACS 2017, IMO)

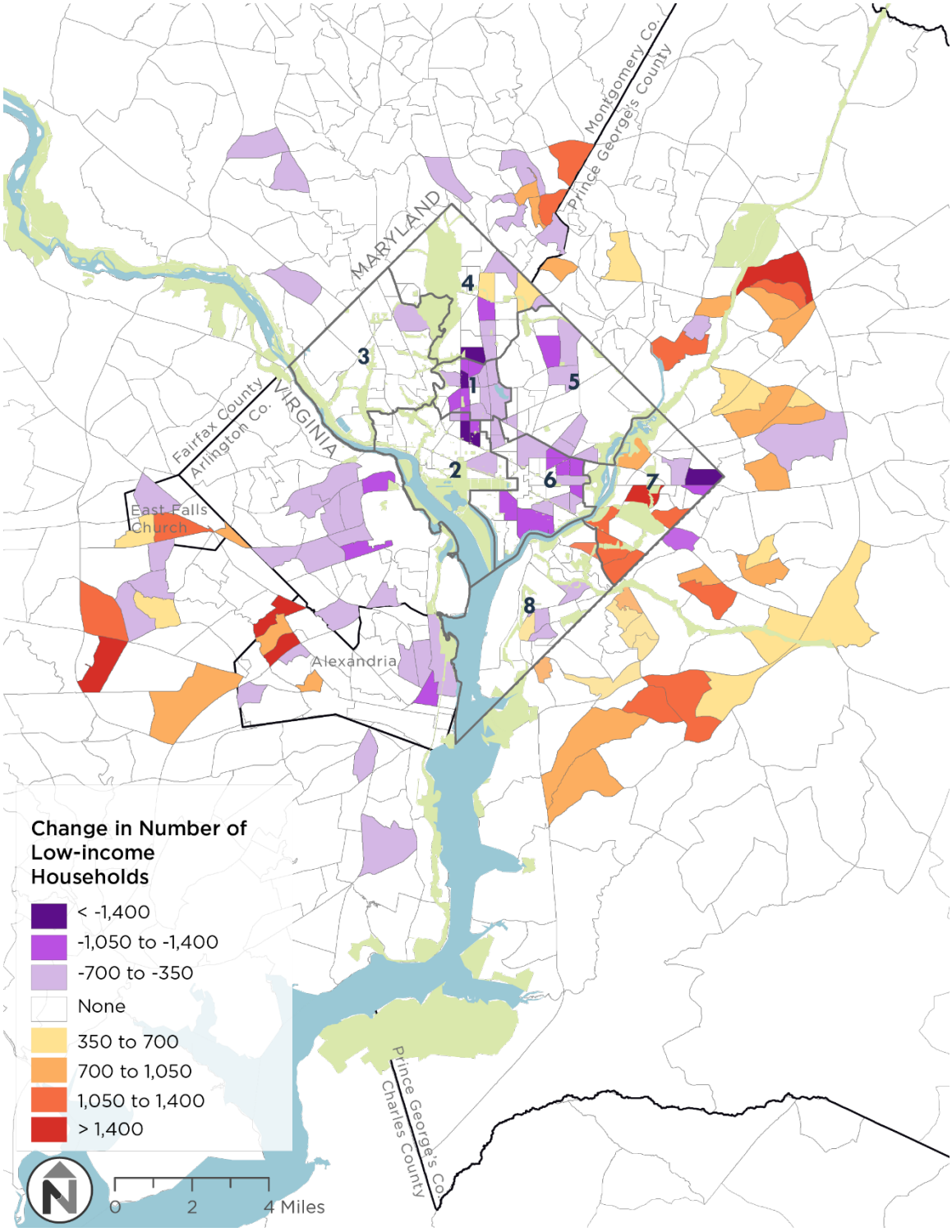
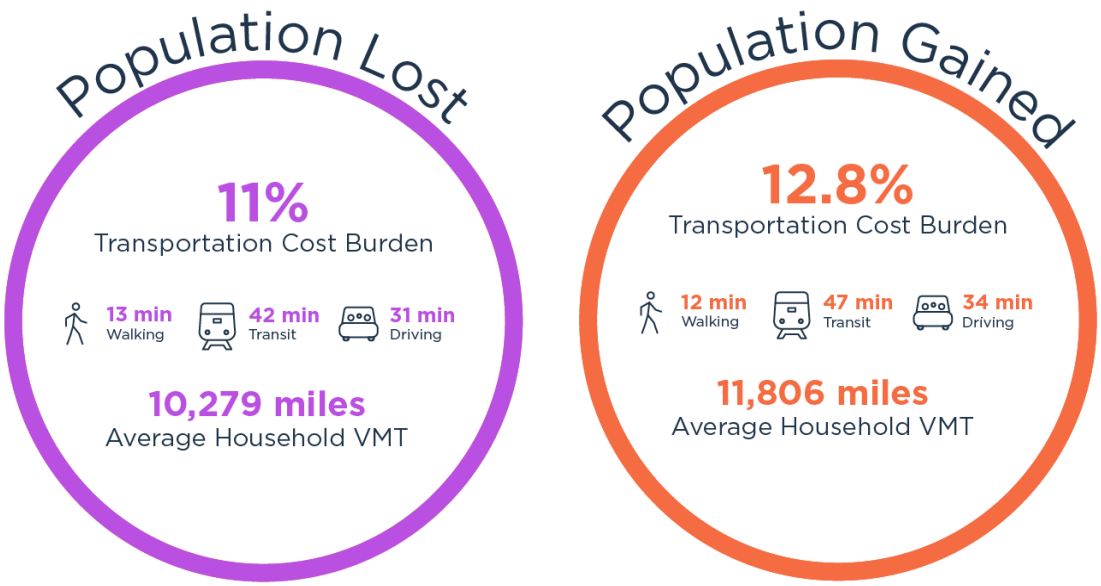


Figure 14 Characteristics of Areas that Lost or Gained Low-Income Household Populations (ACS 2017)



Efficiency

Amount of Driving & Commute Times

DC residents spend an average of 32 minutes commuting. Residents with the longest commute times are located east of the Anacostia River or in northern and northeastern DC, and these same areas are among those with the highest rates of driving (Figure 15).

Census block groups east of the Anacostia River with the longest commutes are majority Black and have average household incomes below the DC-wide average. Parts of Washington Highlands, Bellevue, and Barry Farm in Ward 8, and Fort Dupont in Ward 7, have the highest average commute times in DC with an average commute (by all modes) of 46 minutes, and transit commutes averaging over 50 minutes. Households here are 93% Black and have lower than median household incomes ($27,750/year) as shown in Figure 16 Demographics of Areas with Longest Commute Times and All DC Residents (ACS 2017).

Figure 15 Amount of Driving and Commute Time in DC (OpenData DC, ACS 2017)

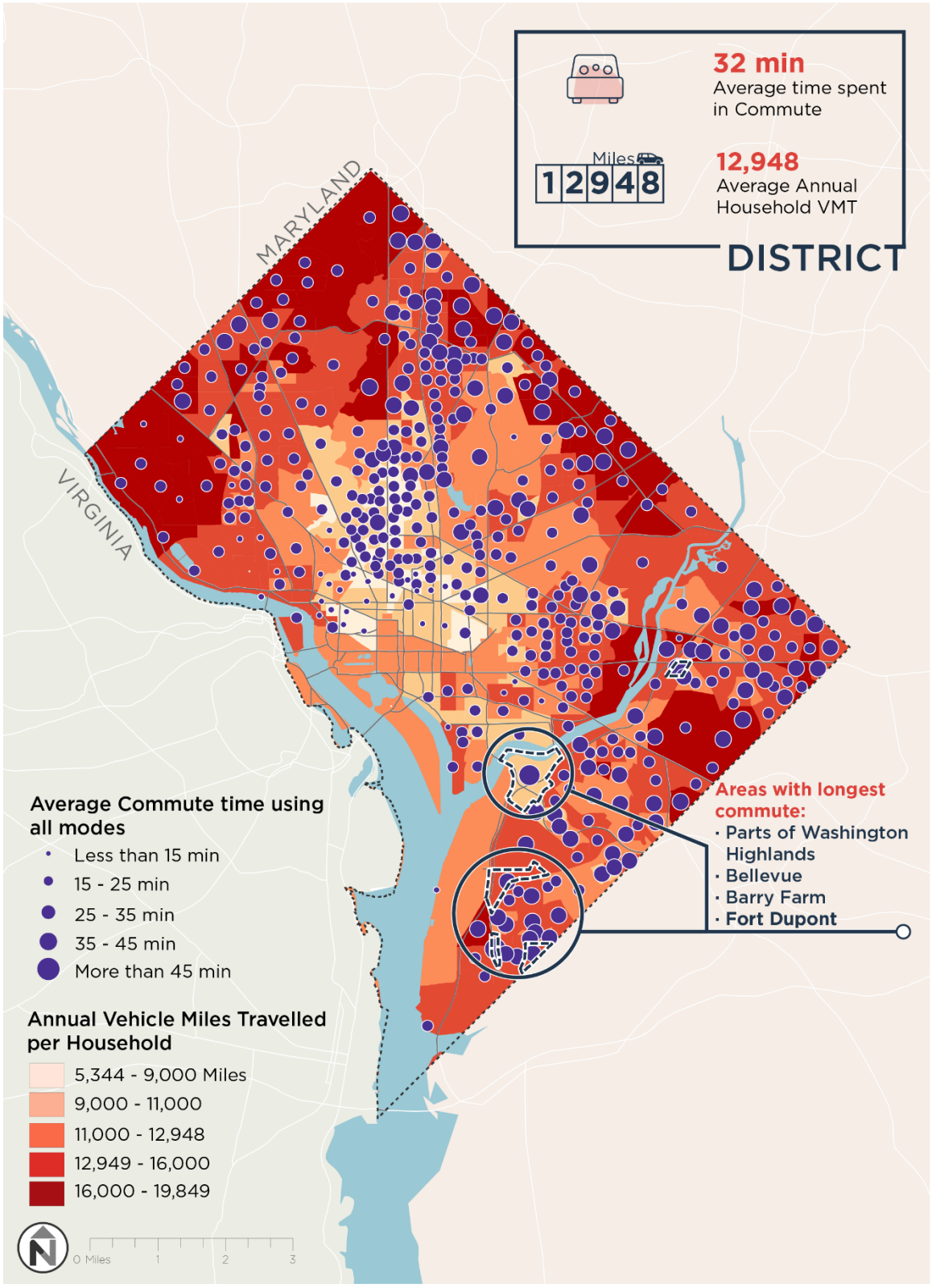
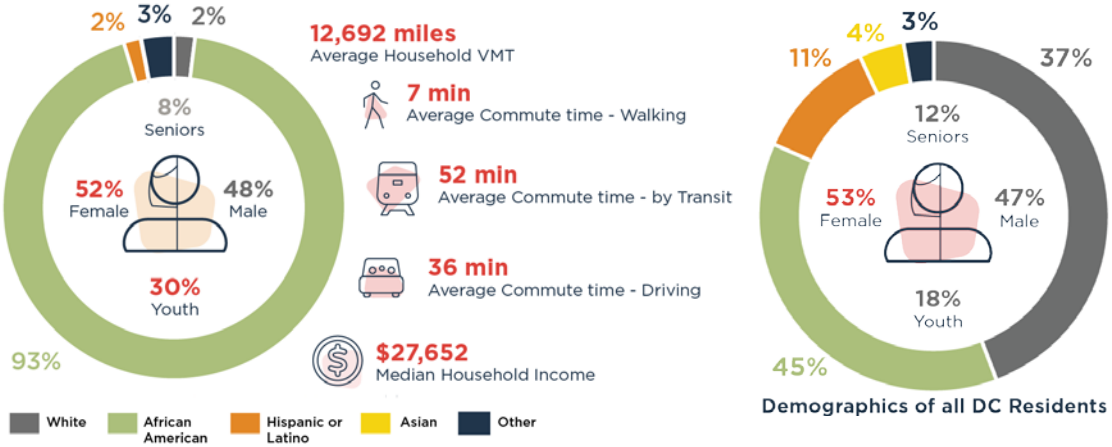


Figure 16 Demographics of Areas with Longest Commute Times and All DC Residents (ACS 2017)



Community Health & Safety

Traffic Safety

Equitable transportation systems are safe for everyone. Walking and bicycling must be safe for people to consider commuting or traveling in general by active transportation modes. Ensuring safe accommodations for people walking or biking can also help to improve mode shift to public transportation, because almost all transit trips – certainly those within DC – begin and end on foot or bike.

Between 2015-2019, 62 people were killed in traffic collisions while walking, biking, or riding a scooter in DC. Fatalities from traffic collisions have occurred along corridors with high vehicle volumes where adequate pedestrian and bicycle facilities are lacking and in dense downtown areas. Ward 2 had the most non-motorized fatalities recorded (18 people walking or on scooters and two people biking), followed by Ward 5 (11 walking or on scooters and three biking) (see Figure 17).

Figure 17 Pedestrian and Bicyclist Fatalities by Ward, 2015-2019 (OpenData DC, Vision Zero Collision Data)

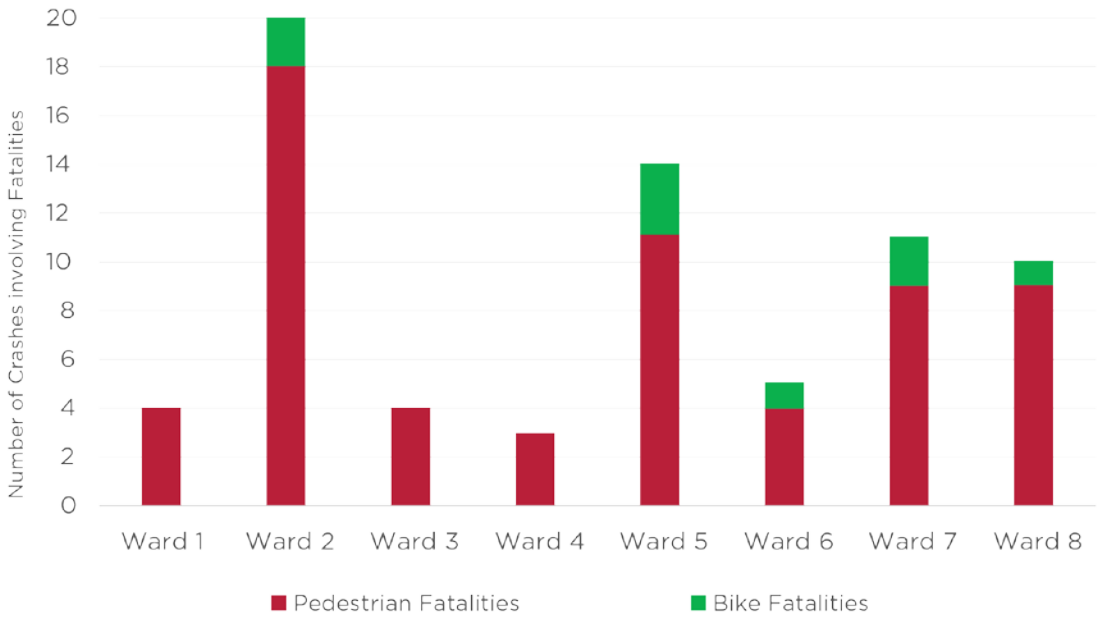
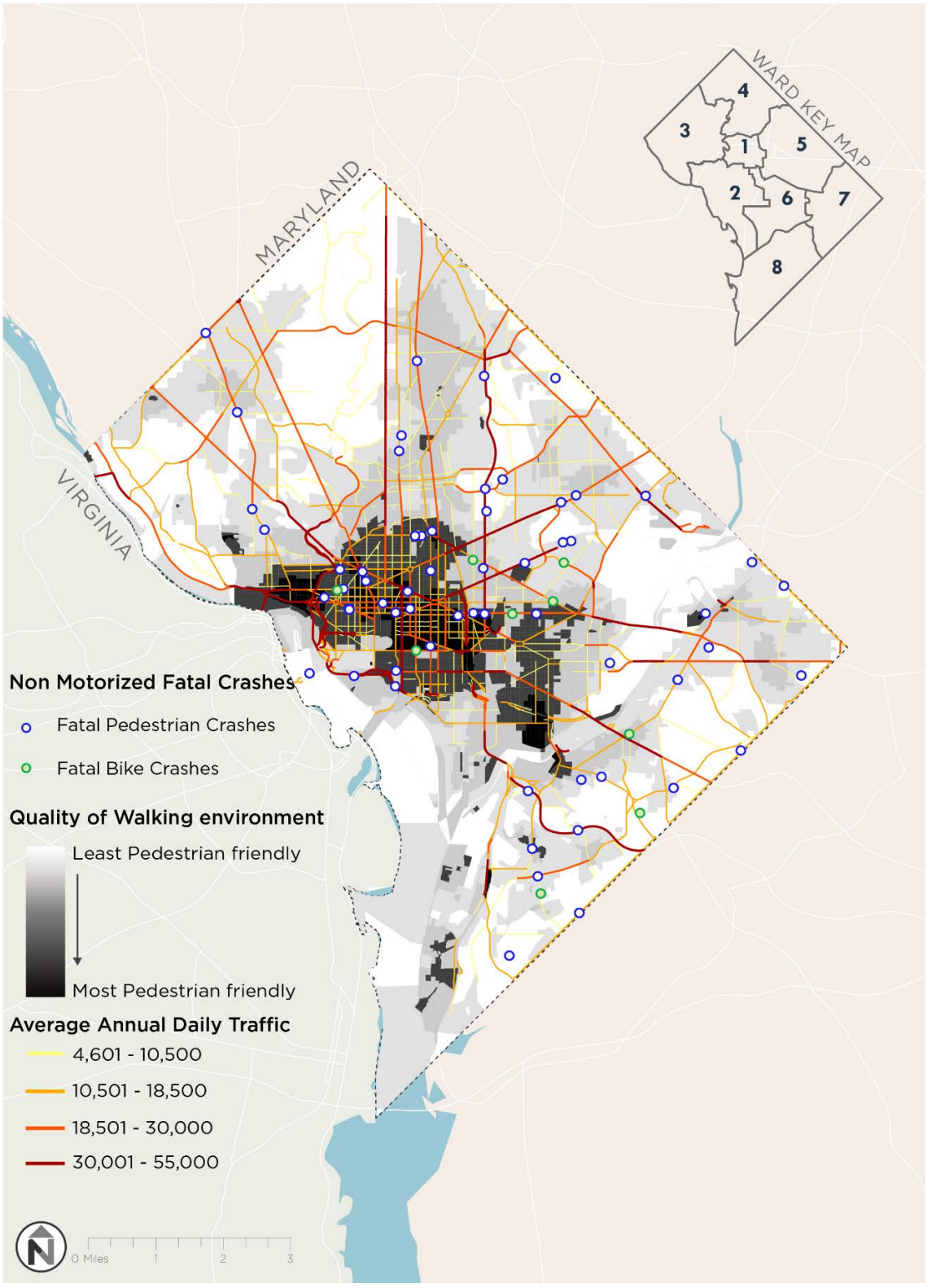


Figure 18 shows the locations of pedestrian and bicycle fatalities and serious injuries that occurred between 2015-2019. The shading in that map represents DDOT's pedestrian friendliness index (PFI) at the neighborhood block level. A number of factors combine to result in a PFI rating for a neighborhood block, including connectivity and accessibility. Large portions of Wards 3, 4, 5, 7, and 8 have low PFI ratings. Despite similar urban form and street network connectivity in all five wards, the number of traffic fatalities varies possibly due to the presence of high-volume arterials. High volume arterial roads run through many wards of the city, but the areas around North Capitol Street (Ward 5) and Suitland Parkway (Ward 8), are the sites of multiple pedestrian fatalities. The presence of other high-speed and high-volume arterials, like Wisconsin and Rhode Island Avenues, may be partly responsible for other traffic fatalities across the city.

Figure 18 Walking and Biking Safety and Fatal Crashes, 2015-2019 (OpenData DC, District Mobility Study, Vision Zero Collision Data)



Community Health

Asthma prevalence is often used as a general indicator of population health and can be tied to transportation planning decisions: the Centers for Disease Control and Prevention (CDC) reports that exposure to transportation-related emissions has been linked to health effects including "exacerbation of asthma symptoms."[16] As identified in the DC Health Equity Report, asthma-related emergency room visits are highest in Wards 7 and 8.[17] Overall, the percentage of adults with asthma in DC is significantly higher east of the Anacostia River and highest in areas bordering Suitland Parkway and DC-295 (the Anacostia Freeway)[18] (Figure 19). Other parts of DC including Ward 5 (specifically, areas that straddle the heavily trafficked New York Avenue in Northeast DC) and Ward 1's eastern side (near Georgia Avenue) show higher asthma rates. The Census block groups with the highest asthma rates are predominantly African-American (84%) in neighborhoods of Fairlawn, Buena Vista, and parts of Anacostia (Figure 20); these areas have a low median household income ($27,250), large youth populations (34% of all individuals here are younger than 18) and longer than average commute times.

Figure 19 Asthma Prevalence Among Adults in DC (OpenDataDC, ACS 2017, CDC)

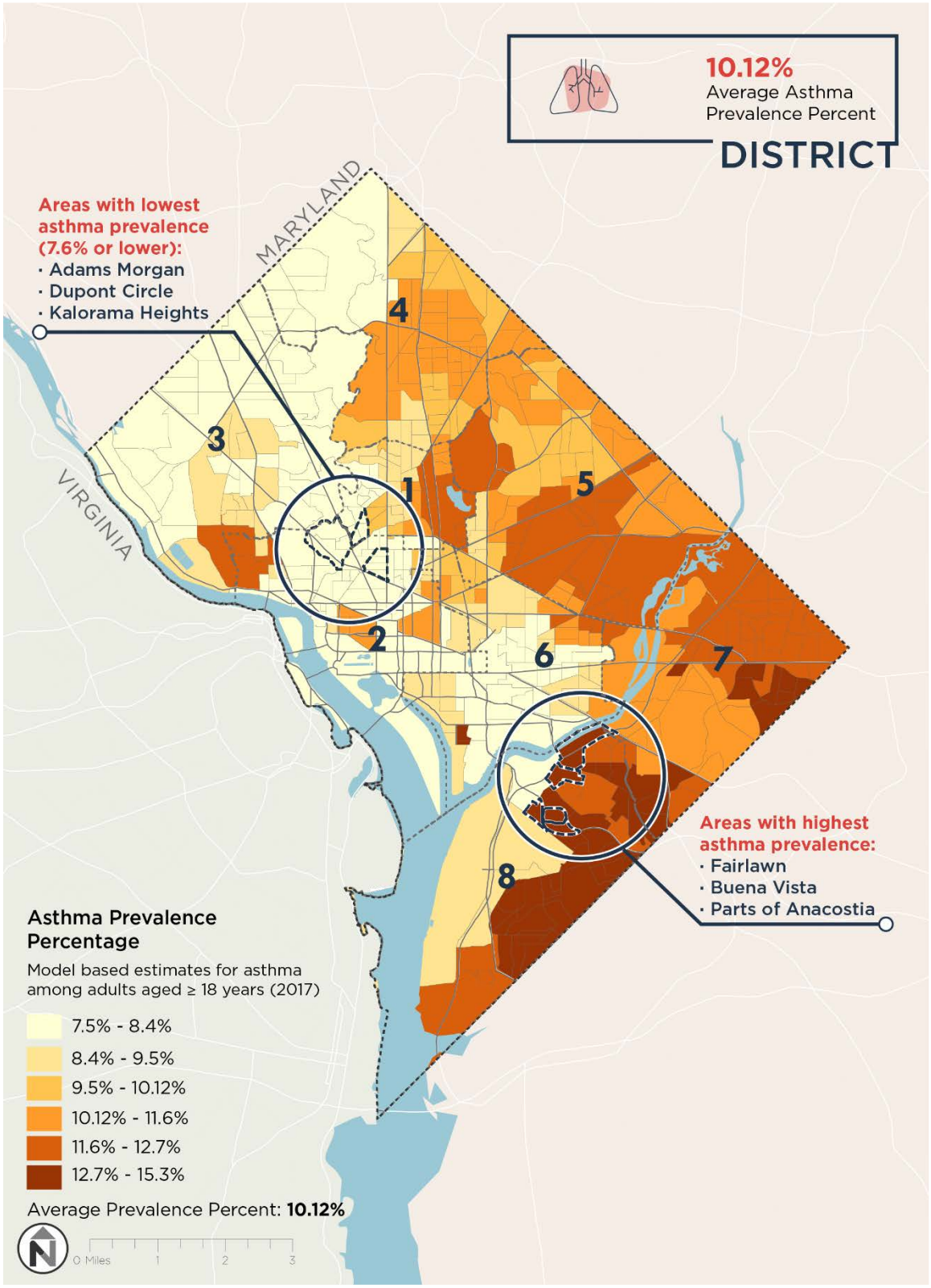
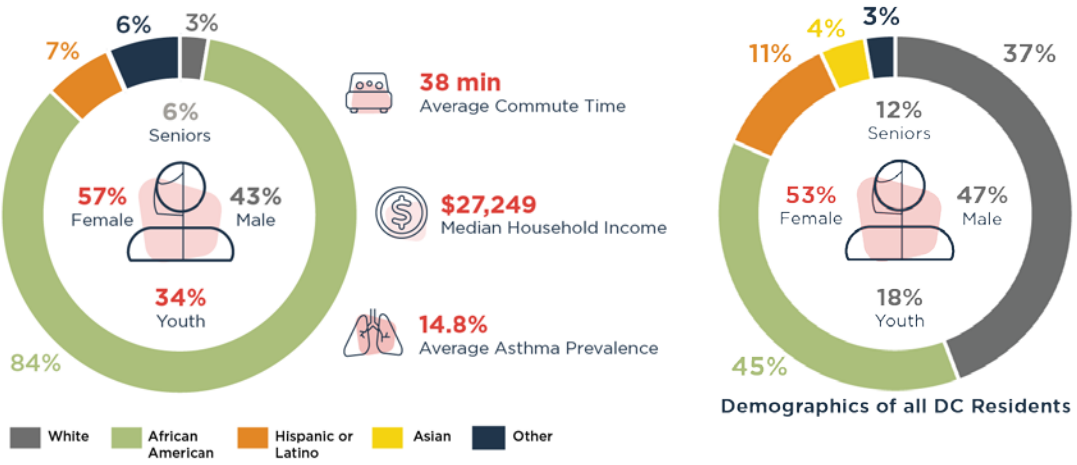


Figure 20 Demographics of Areas with the Highest Asthma Prevalence and Demographics of all DC Residents (ACS 2017)



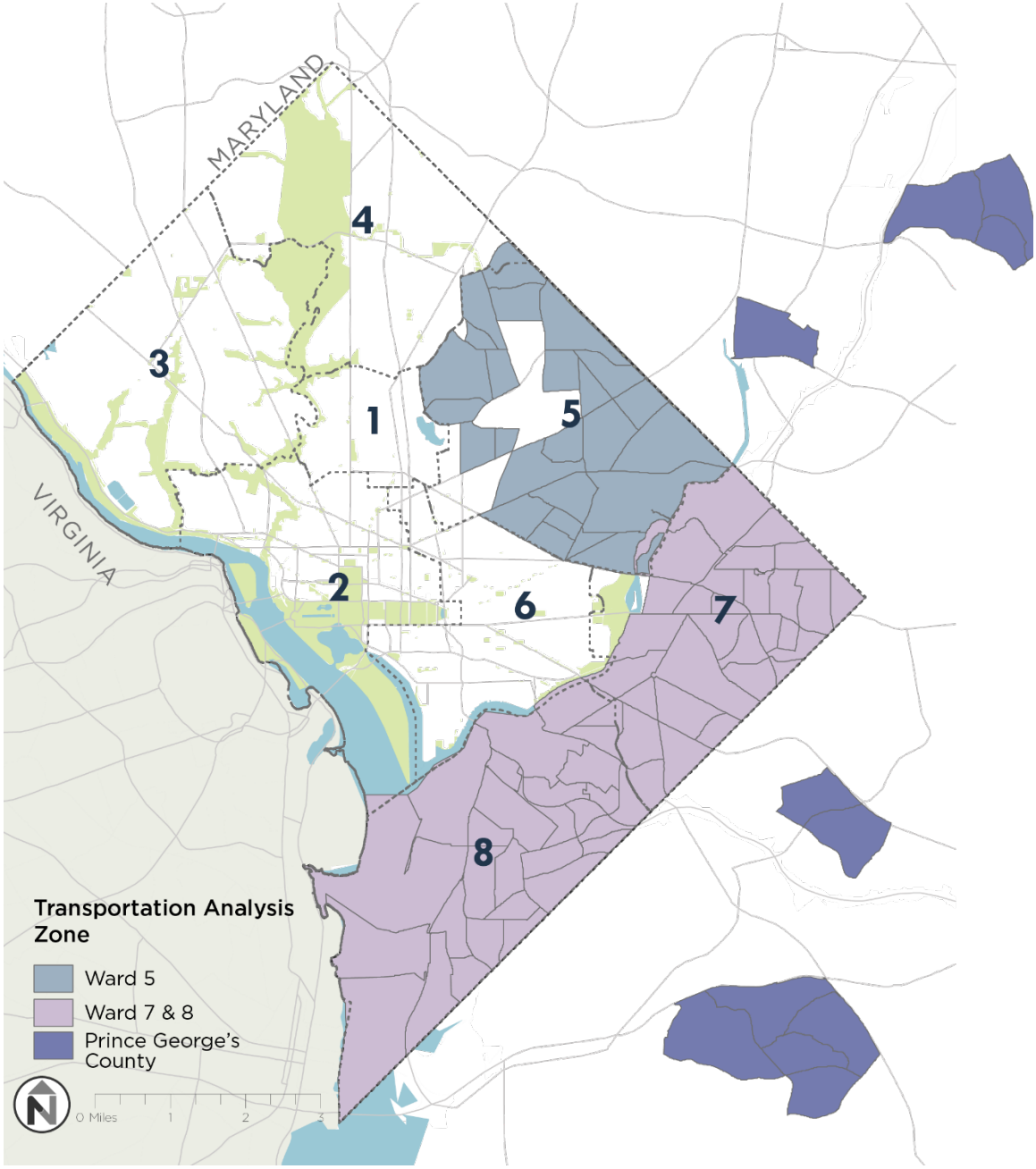
Transportation-Burdened Areas

As this transportation equity analysis shows, people living in specific areas are burdened with longer commute times, greater distances to high-capacity transit, higher transportation costs as a share of income, higher incidences of asthma, and more dangerous roadways for vulnerable users. Neighborhoods and specific Census block groups within Wards 7 (east of the Anacostia River), 8, and 5 are particularly impacted by these factors. Parts of Prince George's County face similar transportation challenges, particularly with regards to access, and have experienced growth in low-income populations over the last decade. Geographies exhibiting transportation burdens are identified in Figure 22 and their main characteristics are described in Figure 21 below. About 23,700 residents live in areas of DC or directly outside of DC (in Prince George's County) within these transportation-burdened areas.

Figure 21 Transportation-Burdened Residence Areas and Characteristics

Transportation-Burdened Residence Areas	Characteristics defining Burdens or Transportation-related Inequities
Ward 5, DC (specific areas)	▪ Longer commutes by transit ▪ Higher incidences of asthma ▪ Lower household incomes ▪ Higher minority populations
Ward 7 & 8, DC (all areas)	
Prince George's County (specific areas)	▪ Displacement-related increase in low-income residents

Figure 22 Transportation-Burdened Residence Areas (OpenDataDC, ACS 2017, IMO)



FUTURE TRENDS

The influx of emerging transportation technologies threatens to exacerbate roadway congestion and a decline in transit use, at the same time that confidence in the reliability of public transportation is declining. Ride-hailing services like Uber and Lyft are growing, with various effects on the transportation system. Autonomous vehicles (AVs), which may arrive in limited numbers within the decade, may also further disrupt urban transportation systems. Because vehicle autonomy is in its infancy and AVs' current, unique contribution to congestion in the District is minute, efforts to determine the effects a congestion pricing policy would have on specifically AV usage and adoption would be futile. However, a recent report led by DCST found that, if DC and the region do not properly manage AVs, an increase in traffic congestion is all but guaranteed.[19] Congestion pricing is a potential tool to manage current congestion and provide a bulwark against future congestion increases. The District of Columbia has finite street space and limited opportunities (or motivation) to increase it. Pricing access to that space can help mitigate congestion while also generating resources to improve access to opportunities for all.

SECTION 3: APPROACH AND METHODOLOGY

Designing a congestion pricing system requires careful consideration of a number of factors. What kind of trips should be charged? How much should they be charged? What are the likely impacts, directly on travel patterns but also on economic activity, health, and other important metrics? It is crucial to consider and mitigate potentially adverse effects to communities within and around the charging area.

Changing the time, cost, or other salient characteristics of travel creates a range of behavioral responses from travelers. Congestion pricing clearly changes the cost of driving, but also changes the time, and in different directions. Many traveler responses contribute to the primary desired outcome, decreased roadway congestion within a designated area or along a designated route.

Some travelers forego trips within charged areas, but those who continue to travel typically respond to congestion pricing in four ways. Travelers may switch to a cheaper mode of travel. Travelers may change their travel time, for example to avoid peak charging times. Some travelers change their destination, but this is usually a less desirable outcome and so charging systems are generally designed to avoid this impact. Some travelers, particularly drivers who cannot change mode or travel time, instead change their route to avoid all or a portion of the congestion charge.

In crafting a plan for congestion pricing in DC, the project team worked with the steering committee to identify the potential charging areas, review congestion pricing tools, and develop charging scenarios that might help DC meet its goals as described in Section 1.

STUDY AREA SELECTION

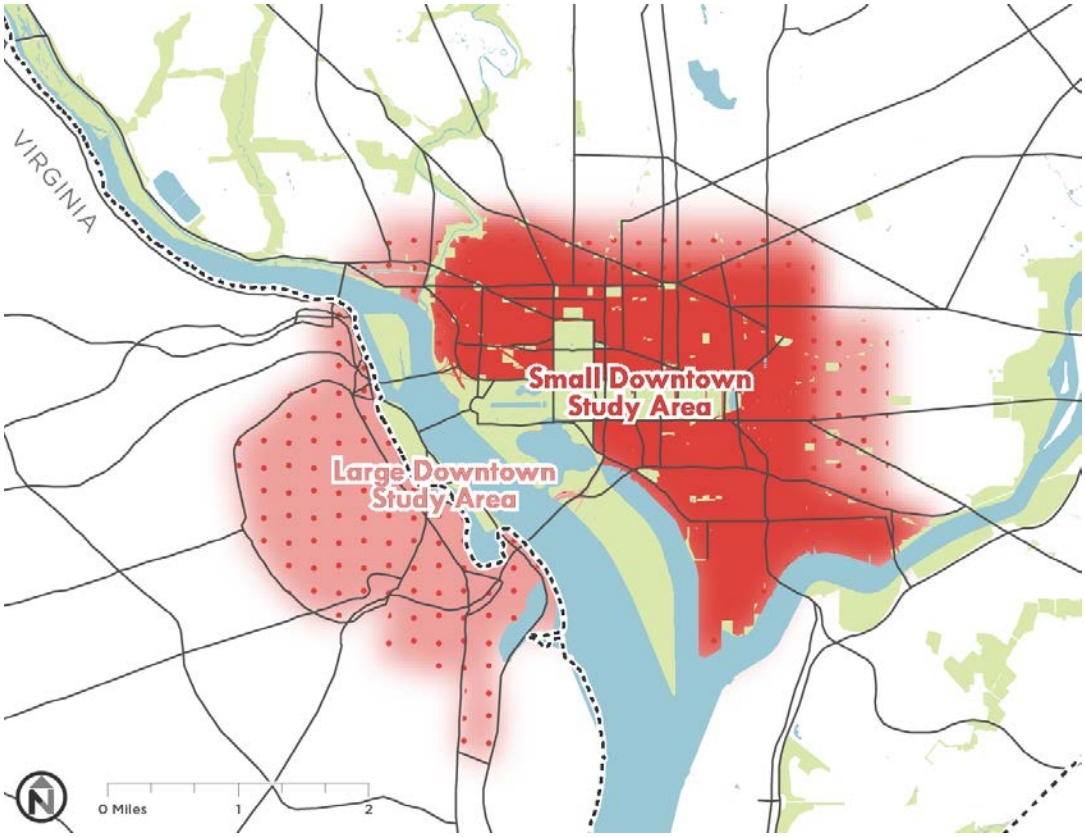
Congestion pricing is typically applied to an area and/or defined road segments that experience notable congestion, either during peak periods or over the course of the day. This study examines three potential pricing areas, chosen to align broadly with areas proposed in previous studies, as described in Section 1. Defining multiple study areas provides the flexibility to adjust congestion pricing strategies according to local context. For example, different pricing scenarios and technologies could be appropriate for a tightly defined downtown pricing zone while others may be suited to pricing specific limited-access highways over a larger area.

It is important to note that for any study area, congestion charges would only be applied to driving trips, not those by transit, biking, or walking. In that way, congestion charging cannot be construed as a “commuter tax,” since it only applies to people who choose to drive. In and around DC, investments in other travel modes have given many people choices of how to travel. Many travelers also have flexibility about when they travel, or whether they drive with others to share the costs of driving.

The specific borders of the two downtown study areas are flexible and could shift several blocks in any direction; general outlines of these areas are shown in Figure 23. The key difference between the two is that one includes a substantially larger area adjacent to downtown DC, plus the key Arlington districts of Rosslyn and National Landing (Crystal

City and Pentagon City). The smaller area was previously highlighted in moveDC, DC's transportation plan published in 2014. The larger area approximates a cordon described in subsequent work led by the Greater Washington Partnership. The third study area is defined by the DC border and includes all of DC.

Figure 23 Conceptual Boundaries of the Downtown Study Areas (OpenData DC, moveDC)



Study Area Descriptions

Small Downtown Study Area

The smaller downtown-focused study area is about 11 square miles, containing the core downtown business districts and waterfront areas. The limits of this charging area are the same as proposed in the moveDC plan; the area includes all of the central business district (CBD) with slight enlargements and modifications near its limits. The area includes the White House and the National Mall from the Capitol Building to 14th Street NW but excludes Union Station. The Potomac and Anacostia Rivers and I-695 would act as western and southern boundaries.

Large Downtown Study Area

An expanded downtown study area includes downtown DC as well as the major employment and growth centers of Arlington's Rosslyn, Pentagon City, and Crystal City districts. Originally identified as a potential congestion zone by the Greater Washington Partnership, pricing in this cross-jurisdictional zone could help manage congestion

around Amazon's future second headquarters site in Pentagon City and Crystal City. Incorporating both DC and Arlington's downtown activity centers would require significant collaboration between the county and state and would result in a more complex cordon zone boundary.

DC-wide Study Area

This area is defined by DC's borders with Maryland and Virginia. Aside from major arterials and its downtown core, much of the area within the DC border does not experience significant recurring congestion, making a cordon-type charge less appropriate for this study area. It would be technically difficult to charge all vehicle entries from this area boundary due to DC's permeable borders with Maryland, and potential political pushback could also pose challenges. This study does not analyze results of a DC-wide cordon charge but allows for its conceptual consideration and provides a useful platform for considering bridge-crossing tolls and other charging methods.

Travel Patterns and Demographics for the Study Areas

Understanding current travel patterns supports analysis of potential congestion pricing impacts. Daily travel patterns are largely determined by where people live and work, and to a secondary extent by the location of schools, shopping, and recreation opportunities. Many additional trips, especially in and near downtowns, are non-commute business trips, service trips, and deliveries.

U.S. Census data from the Census Transportation Planning Products (CTPP) can provide insight into commute trips to a given area. The level of detail of information provided by CTPP is dependent on the geographic size of an area. The three study areas considered here are too small to allow cross-tabulations of multiple demographic factors, but variables available support analysis of commute mode by the income and minority status of the commuter. These data can tell 1) where a study area's commuters come from; 2) the mode these commuters choose on a typical day; 3) the income level of commuters by mode; and 4) the minority status of commuters by mode.

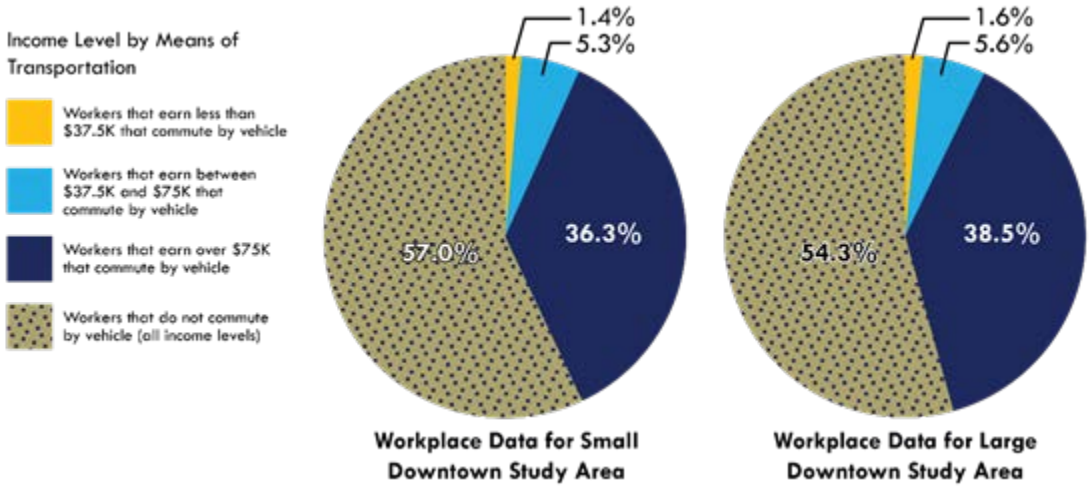
Mode Choice and Income

> If DC were to impose a charge for driving into or within the Small Downtown Study Area, exemptions could apply all low-income workers or all low-income workers that are DC residents. If the exemption applied to all low-income workers, ~6,050 workers would be exempt from the charge, and if the exemption applied to only low-income workers that are DC residents, ~1,770 workers would be exempt from the charge.

Over 400,000 people commute to the Small Downtown Study Area on a typical day. For these commuters, income is strongly correlated with choice of travel mode: 84.4% of driving commuters earn over $75,000 annually, while only 3.3% of driving commuters earn less than $37,500 annually. Only 1.4% (6,045) of all workers within the Small Downtown Study Area have low incomes and drive to work. The income threshold of $37,500 was chosen for this analysis as it is the CTPP income threshold closest to DC's low-income threshold of $36,468 (half the median household income from 2012-2016).[20]

The Large Downtown Study Area shows similar patterns: 84.2% of all driving commuters earn $75,000 or more annually, while 3.5% of driving commuters earn less than $37,500 annually. Only 1.6% (7,962) of all workers in the Large Downtown Study Area have low incomes and choose to drive to work. See Figure 24.

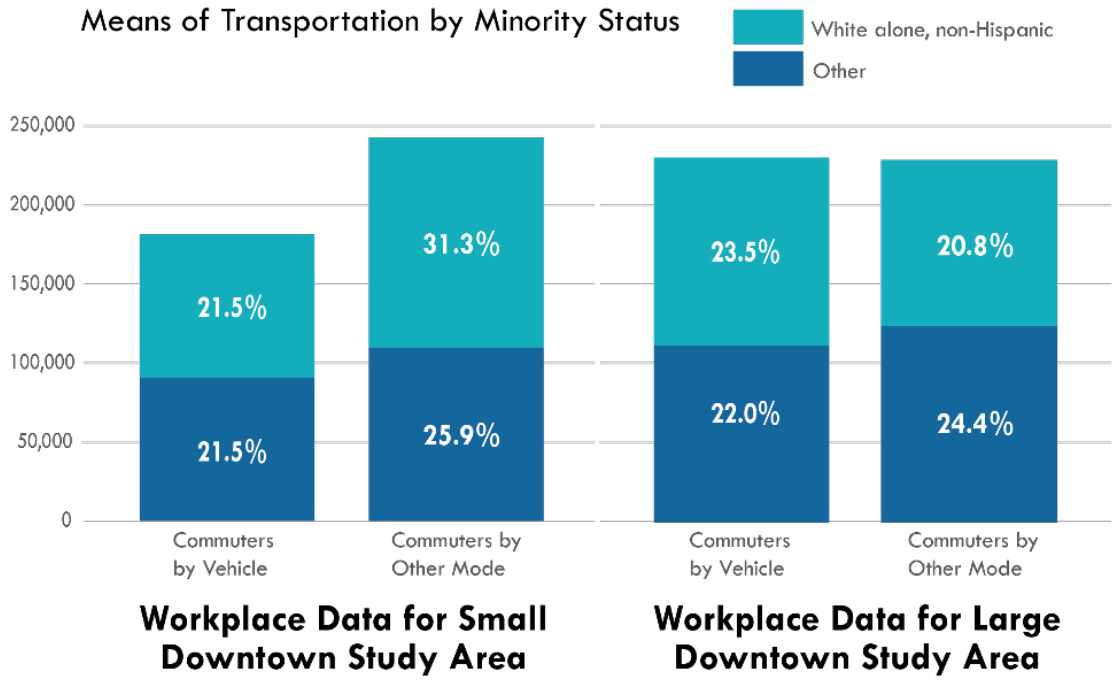
Figure 24 Income Level by Means of Transportation (CTPP 2012-2016)


Income Level by Means of Transportation
Workers that earn less than $37.5K that commute by vehicle
Workers that earn between $37.5K and $75K that commute by vehicle
Workers that earn over $75K that commute by vehicle
Workers that do not commute by vehicle (all income levels)
1.4%
5.3%
36.3%
57.0%
Workplace Data for Small Downtown Study Area
1.6%
5.6%
38.5%
54.3%
Workplace Data for Large Downtown Study Area

Mode Choice and Other Demographics

Minority status does not significantly correlate with mode choice for downtown commuters in DC. In the Small Downtown Study Area, an almost equal share of workers identifies as white and commutes by vehicle (22%) as that identifying as non-white (Other) and commuting by vehicle (21%) – see Figure 25. The Large Downtown Study Area shows a similar trend, where vehicle commuter share is almost equal between minority and non-minority groups.

Figure 25 Means of Transportation by Minority Status (CTPP 2012-2016)



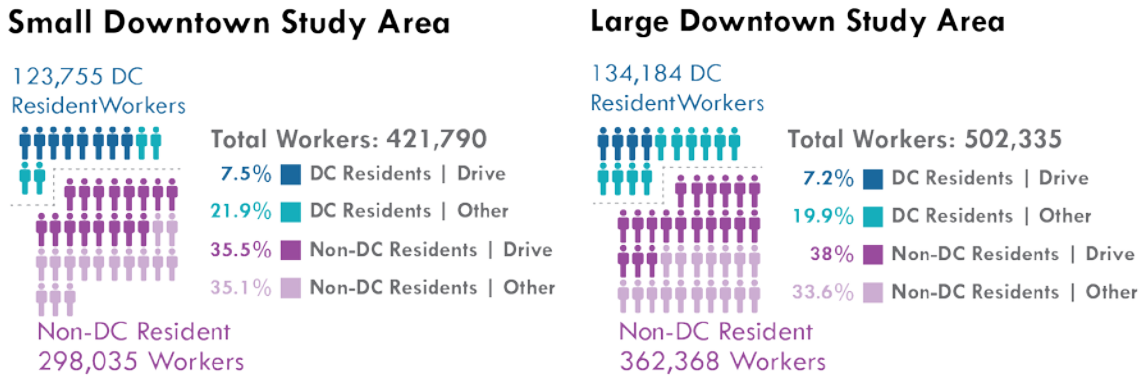
Mode Choice by Location of Residence

Roughly 29% of all workers in the Small Downtown Study Area are DC residents, comprising 124,000 of 422,000 workers. Of all workers commuting to the Small Downtown Study Area, 43% commute by vehicle (either driving alone or carpooling) and 57% commute by other means. Of DC residents, 75% commute by modes other than driving. Commuters living outside DC are evenly split between drivers and non-drivers. Figure 26 shows commuter mode split between vehicle use and non-vehicle use for the Small and Large Downtown study areas, while Figure 27 visualizes this information.

Figure 26 Commute Mode Breakdown of Downtown Study Areas (CTPP 2012-2016)

Total Number of Workers	Commute by Vehicle	Commute by Other Mode	Commute by Vehicle	Commute by Other Mode
Small Downtown Study Area				
421,790	DC Residents: 123,755 (29.3%)		Non-DC Residents: 298,035 (70.7%)	
	7.5%	21.9%	35.5%	35.1%
Large Downtown Study Area				
502,335	DC Residents: 136,184 (27.1%)		Non-DC Residents: 362,368 (72.1%)	
	7.2%	19.9%	38.%	33.6%

Figure 27 Commute Mode Breakdown of Downtown Study Areas


Small Downtown Study Area
123,755 DC ResidentWorkers
Total Workers: 421,790
7.5% DC Residents | Drive
21.9% DC Residents | Other
35.5% Non-DC Residents | Drive
35.1% Non-DC Residents | Other
Non-DC Resident 298,035 Workers
Large Downtown Study Area
134,184 DC ResidentWorkers
Total Workers: 502,335
7.2% DC Residents | Drive
19.9% DC Residents | Other
38% Non-DC Residents | Drive
33.6% Non-DC Residents | Other
Non-DC Resident 362,368 Workers

Mode Choice for Residents of Transportation-burdened Areas

The analysis in Section 2 describes differences in transportation access, affordability, and related outcomes for people living in areas of DC and Prince George's County, which led to the identification of specific transportation-burdened areas. Using CTPP data, the project team analyzed the mode choice of residents of transportation-burdened areas that work in the Small and Large Downtown Study Areas. As stated, about 23,700 residents live within these transportation-burdened areas and work in the Small Downtown Study Area, but not all drive to work: only about 10,000 people who live in the transportation-burdened areas currently drive to work in downtown DC (see Figure 28). This is large number of people - and vehicles - but is a small percentage (~5%) of the total number of commuters driving to downtown DC. These findings also indicate that most workers in these burdened areas do not commute by car to downtown DC; only about 10% of workers living in these areas would be impacted negatively through required payment of a downtown congestion pricing charge. Meanwhile, a much larger number of persons (23,700, which is over a quarter of the workers in these areas) commute to downtown DC and are already negatively impacted by unmitigated congestion through delayed driving trips and/or bus trips.

While the number of low-income drivers is not large, adding additional costs to their commutes would disproportionately add to their burden (albeit in exchange for an improved travel time). Targeted exemptions from congestion pricing can ensure they get the maximum benefit from the system without a significant impact to congestion pricing revenues.

Figure 28 Residents of Transportation-Burdened Areas Working in the Small Downtown Study Area (CTPP 2012-2016)

Residence	Characteristics defining Burdens or Transportation-related Inequities	Work in Study Area	Drive to Work in Study Area
Ward 5, DC (specific areas); *25,560 total worker population*	Longer commutes by transit Higher incidences of asthma Lower household incomes Higher minority populations	7,140 *27.9% of total population*	2,640 *10.3% of total population*
Ward 7 & 8, DC; *54,040 total worker population*		14,590 *27% of total population*	6,410 *11.9% of total population*
Prince George's County (specific areas); *15,215 total worker population*	Displacement-related increase in low-income residents	1,970 *12.9% of total population*	1,080 *7.1% of total population*
Residents of Transportation-Burdened Areas Working in the Small Downtown Study Area; *94,815 total worker population*		23,700	10,130
Total Workers in the Small Downtown Study Area		421,790	181,439

SCREENING AND SELECTION OF PRICING TOOLS

A key part of this study involved the evaluation of available congestion pricing tools to determine which best meet the goals of providing congestion relief, reducing transportation emissions, and improving health and equity. A handful of cities have congestion pricing programs and offer insights into possible congestion pricing methods. Each method is variously applicable to DC's goals and objectives, and the steering committee's feedback helped the project team and DCST select the pricing strategies that would be further analyzed in the study.

Ultimately, several pricing tools may be combined to achieve DC's congestion management objectives. A mix of pricing tools and discount strategies will make congestion pricing more complex (and make it more complicated to communicate, implement, and enforce the program), but pricing tools must be fine-tuned to work within a specific geography, jurisdiction, and transportation network. The tools discussed with the steering committee and the feedback provided are listed Figure 29.

Figure 29 Pricing Tools Summary

Pricing Tool	Description of Pricing Tool	Location where Pricing Tool is in Effect	Decision to Study Further
Cordon Pricing *(see Figure 30)*	Charge vehicles for crossing a boundary into pricing zone	Singapore (implemented): ▪ Implemented in 1998. ▪ Congestion pricing has been a major component of traffic management and emissions reduction plans since 1975.	**Yes.** Cordon pricing should be studied for DC, focusing on study areas previously identified in project reports.
Area Pricing *(see Figure 30)*	Charge vehicles for crossing a boundary ***and*** for driving inside a pricing zone	London (implemented): ▪ Implemented in 2003. ▪ Prior to adoption, funding for public transport was unreliable and congestion levels in central London were extremely high.	**Yes.** Area pricing should be studied, with care to provide options for vehicles that prefer flat cordon fee.
Fleet/Vehicle Class Pricing *(see Figure 30)*	Charge specific vehicle types entering a zone, such as ride-hailing or commercial vehicles	London (implemented within area pricing) New York City (in litigation): ▪ Fleet/Vehicle Class Pricing is phase two of a three-phase congestion pricing approach. ▪ Fleet pricing applies to taxis and other ride hailing services.	**No**. Studying the effects of fleet/vehicle class pricing on its own is not a priority.
Fossil Fuel Free Zone (FFFZ)	Create a zone that allows only licensed non-fossil fuel vehicles	London (implemented) Milan (implemented): ▪ Cordon pricing was implemented in 2012, including a low-emissions zone. In addition to applying a charge for all vehicles entering the zone, other restrictions and exemptions apply*	**No**. Studying a pricing strategy specifically targeted towards fossil fuel free vehicles is not a priority, as this approach would not affect enough vehicles currently driving in the DC area.
License Plate-Based Restriction Zone (LPRZ)	Restrict access to a zone based on license plate numbers	Sao Paulo (implemented) Mexico City (implemented): ▪ Launched in 1989, with expansions in 1990 and 2016. Cars are prohibited from driving in the city on certain days based on the last digit of their license plate (e.g., license plates ending in a 3 or 4 cannot drive on Wednesdays).	**No.** Studying this pricing strategy will not help to achieve the full range of goals that are desired for a DC congestion pricing program. LPRZs are generally implemented specifically for congestion mitigation or as an air quality management tool; this approach would be less effective at encouraging mode shifts and could further burden disadvantaged communities.
Road Usage Charge (RUC)	Restrict access to a zone to vehicles enrolled in a RUC program that	Washington State (piloting):	**No.** Studying this newer pricing strategy is not a current priority. Due to

Pricing Tool	Description of Pricing Tool	Location where Pricing Tool is in Effect	Decision to Study Further
(see Figure 30)	replaces fuel tax with a per-mile charge, by time of day, and/or location	▪ Completed a 2,000-driver pilot of a road user charge program in January 2019. ▪ Participants chose one of four options for reporting their mileage: pre-selected mileage block, quarterly odometer readings, plug-in mileage meter, or smartphone app.	DC's permeability with Virginia and Maryland, a statewide effort within DC would not be able to address the majority of DC's congestion issues. More regional efforts are underway: the Eastern Transportation Coalition (TETC) is studying the potential for a mileage-based user fee through pilot studies.[21]
Arterial Toll Roads	Tolling urban arterials is similar to tolling a highway, but to date, this has only occurred as part of Singapore's cordon pricing program. Tolling the length of an arterial is considered more complex than tolling a highway because of the numerous access points and potential for traffic diversion onto other urban streets.	Singapore (implemented): ▪ Implemented electronic road pricing technology in 1998. ▪ Vehicles are charged while passing under overhead gantries. ▪ The fee varies based on vehicle type, time, and location.	**Yes.** Interested in studying a variant of this approach where cut-through (or pass-through) traffic is charged, while local users are not. Existing electronic toll collection technology could support such a concept.
Arterial Express Lanes	Toll existing or new lanes on arterial roads. Restricted access in arterial lanes is currently common for the development of bus-only lanes, such as those in downtown DC. Like express lanes on freeways, arterial express lanes would restrict access to those who meet vehicle and occupancy eligibility requirements or to those paying a toll.	Tampa (study): ▪ Conducted a proof of concept study of a Bus Toll Lane (BTL) focused on limited access corridors as a partnership between transit and toll agencies with a revenue sharing model. ▪ Tolling equipment, similar to that used on freeway express lanes, would be required for implementation.	**No**. There are few opportunities in DC where excess arterial lanes could be converted to toll lanes without extensive infrastructure redesign. In absence of redesign, this approach would require reliance on enforcement, an added cost. Studying this approach is not a priority.
On-Street Parking Pricing	Vary street parking prices to control demand. A combination of smart meters, embedded parking sensors, and traveler information systems are used to manage parking pricing in near real time.	San Francisco (implemented): ▪ Launched in 2011, with expansion citywide in 2018. ▪ Smart parking meters update pricing within a $0.75 range per hour. ▪ Pricing is adjusted by block, based on time, location, and day of the week.	**Yes**. Interested in studying this strategy by exploring the potential impacts of pricing parking to reduce congestion or encourage mode shift. Demand-based on-street parking pricing has already been tested in DC: in the Penn Quarter/Chinatown neighborhoods DDOT monitors and provides real-time updates on occupancy at 1,000 spaces. DDOT adjusted prices quarterly, with prices currently ranging from $1 to $7 per hour, depending on the block and time of day.

Pricing Tool	Description of Pricing Tool	Location where Pricing Tool is in Effect	Decision to Study Further
Off-Street Parking Pricing	Apply a variable fee/tax to off-street parking facilities. By leveraging existing parking payment infrastructure, pricing off-street parking could be a low-cost approach to demand management. The prices could influence regular commuters because they would apply to monthly parkers and other regular drivers.	San Francisco (implemented): ▪ Citywide smart parking meter program is also used in operation of SFMTA-owned off-street garages and lots. ▪ Rates at SF park off-street facilities vary by time of day and are updated quarterly based on demand.	**No.** Studying this strategy is not a priority due to limitations on DC's control of privately-owned off-street parking. This approach should be explored when investigating policy shifts or larger travel demand management (TDM) programs in the city.

*Restrictions and exemptions that apply: 1) Vehicles using gasoline Euro 0 or diesel Euro 3 or below are prohibited from entering. 2) Private vehicles longer than 7.5 meters (24.6 feet) are also prohibited. 3) Electric vehicles, motorcycles, scooters, public transit vehicles, public utility vehicles, emergency vehicles, taxis, and vehicles for people with disabilities are exempt from the charge.

Figure 30 Pricing Tools and Infrastructure (from left, clockwise): Tolling gantry with transponder and license plate camera; Oregon's OreGo RUC program; Truck tolling equipment in Germany

The above comparison narrowed the range of congestion pricing strategies to be considered for implementation in DC, described below.

Selected Pricing Tools and Scenarios

Cordon Pricing

Cordon pricing is the concept of charging vehicles a fixed or variable toll for entering and/or exiting a congested zone within a city. Pricing can vary according to vehicle type (e.g. private or commercial vehicles, cars, or trucks) and by time of day (e.g., depending on traffic conditions). Typically, tolling equipment is placed on all roads leading into and out of a cordon zone. Toll collection equipment at cordon boundaries identifies vehicles using toll transponders and/or license plate recognition camera systems, and toll amounts are either deducted from toll accounts or are sent to vehicle owners as toll invoices.

This study identified two types of cordon pricing scenarios to be tested on both downtown study areas: an inbound-only and an inbound/outbound charge scenario. With an inbound-only charge, vehicles are charged only when they enter the cordon zone. With an inbound/outbound charge, vehicles are charged whenever they cross the cordon, regardless of whether they are entering or exiting the cordon zone.

Benefits of a cordon pricing scenario include ease of implementation (relative to area pricing scenarios as described below). Cordon pricing is also easy to explain to road users and has been effective in other cities, which can help when explaining its benefits to the general public.

Inbound-only charging is generally easier to implement and explain than inbound/outbound charging, with similar impacts. Inbound/outbound charging will have higher implementation and operating costs. The main reason to consider inbound/outbound charging is that it can encourage travelers to choose different modes (or non-peak travel times) for each half of a round-trip independently, which can lead to additional shifts in travel behavior resulting in reduced congestion.

Limitations of Cordon Pricing Approach

The location of charge points for a cordon-based approach would need to be carefully chosen to avoid unwanted boundary effects, such as diversion that could increase traffic on streets or in areas adjacent to the cordon boundary. Furthermore, since drivers are charged a flat fee for any trip that crosses the cordon, even if it ends just inside the cordon, parking demand may increase in areas just outside the cordon, another undesirable behavioral result from congestion pricing. Other considerations for cordon pricing specific to DC are potential impacts that charge point infrastructure may have on historic viewsheds; installation of charging equipment will require review and/or approval by national organizations (described in detail in the following sections).

Area Pricing

Area pricing is similar to cordon pricing but charges for the amount of driving within a pricing zone, instead of or in addition to charging for crossing the zone's boundary. This approach is best suited for geographically large pricing zones where vehicles driving within a zone may not necessarily cross the zone's boundary but still contribute to congestion. Area pricing relies on tolls collected electronically with tolling equipment placed at strategic locations within a pricing zone as well as at its boundaries. In the

near future, area pricing may use in-vehicle technologies that would potentially eliminate the need for external sensor locations. Without full adoption of in-vehicle tolling technology however, cordon pricing technology would still be required to ensure all trips paid an appropriate charge.

Area pricing can make a pricing structure fairer since it applies to those within the cordon as well as those traveling into the congested area. With more tolling infrastructure, area pricing is more complex and has higher capital and operating costs. As the congested area (and the area priced) grows larger though, area pricing can cost-effectively expand the benefits of congestion pricing.

Area pricing also can reduce the boundary effects of cordon pricing, as a trip traveling only a small distance within the priced area would pay a smaller charge than the equivalent fixed cordon charge. This approach makes charging more equitably connected to congestion impacts and could reduce the demand on roads and parking just outside a cordon. From a political perspective, the “softer” boundary effects of area pricing can reduce the pressure on exactly where the boundary for a priced area is drawn.

Area pricing can be applied to the amount of time driven within the priced area, or alternatively the amount of distance driven. A time-based approach should be easier to implement technologically, as it requires only the tracking of entry and exit time as a vehicle crosses the area boundary. This could occur as part of the same hardware required for cordon pricing.

An area-based approach would require rules for vehicles that stay overnight or otherwise enter or exit the area outside of tolling periods (if tolling charges were limited to specific times of the day). This accommodation is familiar to anyone who has parked at an airport or other long-term facility that caps daily charges. A downside to pricing by time is that it could create a perverse incentive for people to limit the amount of activity (including beneficial non-travel activity) within the priced area. It could even incentivize speeding, although that seems likely a marginal impact given that speeds downtown are slow by design and policy as well as due to congestion.

Area pricing based on distance driven seems more attractive, as only moving vehicles are charged, and they are the ones that directly contribute to congestion. It would also discourage circling for parking, which contributes substantially to congestion in downtown DC. This removes the incentive to limit activities within the priced zone and also any incentive to speed to minimize time. Implementation of area pricing by distance requires more monitoring, as stated above. Accurately tracking distance requires either on-board units (OBUs), or extensive coverage of the street network *inside* the priced area with monitors plus an analytic back-end to estimate distance driven from multiple point reports. On-board units are communication devices mounted on vehicles which collect data about a vehicle’s trip in order to transmit that data to OBU sensors and determine the required toll payment.

Limitations of Area Pricing Approach

Area pricing elicits privacy concerns, as additional tracking is needed to accurately monitor and price travel within a congestion pricing area. This type of monitoring could be achieved (for area pricing by time) with an OBU, which would be scanned during

entry or exits of the area. A maximum daily price could be charged to cover vehicles that stay within the zone for longer periods. Due to privacy concerns, the prevalence of visitors, and the likelihood that not all drivers would opt for an OBU, area pricing scenarios could assume a hybrid situation, where a portion of private vehicles are charged a flat fee, while others that opt to use an area pricing mechanism pay the by mile or by minute charge. Delivery vehicles and ride hailing vehicles, on the other hand, could be required to use an OBU, since registration and fees for these commercial vehicles should allow an avenue for mandatory requirement.

The study team identified an area pricing/cordon pricing hybrid scenario to be tested for both downtown study areas.

Bridge Tolling

This scenario considers charging bridge traffic that crosses the Potomac River into DC along Interstate 66 and express lanes on Interstate 395, roadways which already have tolling mechanisms on the Northern Virginia side. Incorporating bridge tolls is functionally a cordon charge for vehicles entering DC on these specific travel lanes.

Limitations of Bridge Tolling Approach

Because this scenario is restricted to already-tolled facilities, it can only price a fraction of the vehicle trips coming into downtown DC. These two bridges only connect Arlington, VA, to DC, while other entry points to DC from Virginia – and all driving routes from Maryland – would remain uncharged. These uncharged access points into DC would provide ample opportunity for diverting routes into DC and weaken chances for behavioral changes such as mode shift or change of travel time. The uneven focus of tolls at DC's border with Virginia could also undermine a core congestion pricing goal for more equitable charging.

Carpools are currently exempt from charges on these tolled facilities in Virginia, so DC may need to consider exempting carpoolers from these proposed bridge tolls. Providing exemptions to carpools has not been considered in this study.

Pass-Through Traffic Tolling

A traditional arterial tolling scenario was not analyzed, at the direction of the steering committee. Most of DC's arterial streets are well-connected to the surrounding street network and serve a combination of local and through traffic. Imposing congestion charges for travel on those arterials could easily result in trips diverting to the local street network. In addition, current technology would require very frequent roadside sensors along the length of an arterial to ensure all trips are charged.

However, the steering committee felt that addressing arterial roadway use by charging pass-through travelers was one of the critical issues in mitigating adverse effects of traffic in DC. The I-295 corridor and US-50/New York Ave NE corridor pass through areas with some of the highest rates of asthma in DC and have a significant number of pedestrian and bicyclist collisions and fatalities. Tolling would not only reduce congestion but would also encourage through travelers to change their route so that they do not pass through DC.

A pass-through traffic tolling scenario was tested to charge only vehicle trips that enter and exit DC within a short time frame. Other vehicle trips that enter DC but remain in the area for a longer time period would not be charged, on the principle that they are likely contributing to economic activity in the DC.

Limitations of the Pass-Through Traffic Tolling Approach

A pass-through traffic tolling scenario would likely result primarily in trip diversion or departure time changes and would less likely cause significant mode shift. A congestion scenario such as this has not yet been implemented, but existing technology could be used to achieve this temporal charging approach.

On-Street Parking Pricing

Variably priced on-street parking can be used to manage demand for parking and by extension, congestion. Pricing on-street parking introduces a price signal that encourages turnover of high-demand parking spaces and increased utilization of low-demand parking spaces and can thus reduce the time drivers spend circling to look for parking. If prices increase significantly and consistently, this can encourage some drivers to switch modes of travel. San Francisco leads the nation in actively managing parking prices, as it controls and manages both on- and off-street parking facilities. DC could only implement an on-street parking pricing program as very few off-street parking garages and lots in downtown DC (or Arlington) are owned or managed by the local government. Such a program would be less effective in reducing congestion and meeting other goals.

Although parking pricing alone may not be enough to significantly impact roadway congestion in DC, it can be combined with other congestion pricing programs to amplify congestion-reduction benefits. The District of Columbia has successfully implemented an effective on-street pricing pilot program in a portion of downtown DC. A combination of smart meters, embedded parking sensors, and system data are used to adjust parking pricing quarterly to maintain parking space availability.

A hypothetical on-street parking pricing scenario was tested as part of this study to estimate the potential effects of a standalone parking pricing increase.

Limitations of the On-Street Parking Pricing Approach

Changing on-street parking pricing alone is unlikely to have a large impact on transportation mode choice during the peak congestion periods. Many workers do not park on-street and rather use off-street parking lots or garages at daily rates (or free of cost). The lack of control of off-street parking supply and pricing restricts the amount that a jurisdiction can change behaviors through parking pricing alone; instead, TDM programs are often the mechanism that jurisdictions can use to encourage shifts in travel mode.[22] Despite the limited influence over off-street parking, better management of on-street parking provides a great opportunity for cities and jurisdictions. Curb lanes can be converted into more productive uses such as pick-up and drop-off zones, transit-only lanes, or protected bicycle and micro-mobility lanes. These conversions will decrease the supply of parking and could be paired with dynamic, competitive pricing to maintain optimal utilization of the remaining spaces.

CONSIDERING TECHNOLOGY FOR PRICING

Congestion pricing technology will play an important role in any pricing scheme for DC. The technology will perform two primary functions: accurately and correctly charging travelers and ensuring that travelers make payments and obey restrictions. To adequately charge and enforce, a pricing system should include the following elements:

1. **Vehicle identification devices:** In addition to using images of vehicle license plates, systems can use devices attached inside or outside a vehicle, integrated with a vehicle, and/or carried by drivers and passengers to identify vehicles.
2. **Roadside detectors and enforcement equipment:** Most systems use field devices on the roadside or over the roadway to detect vehicles, whether they are paying travelers or scofflaws. Emerging systems using cell phone and GPS technology obviate much of the need for roadside detectors, although they remain necessary in tunnels and some other urban conditions.
3. **Administrative activities:** Technologies are required to manage customer accounts, process transactions and payments, interface with other external systems (e.g., Department of Motor Vehicles), conduct audits and financial reconciliations, set prices, and monitor performance.

When considering a technology system to support a preferred pricing program, DC should assess the following:

4. **Technology maturity** – Deploying existing technologies will likely be less expensive and risky than deploying emerging technologies. However, existing technologies carry the risk of becoming obsolete or vulnerable to market disruptors. The District of Columbia should avoid proprietary technologies to reduce the risk of high costs from a sole source procurement.
5. **Physical footprint of infrastructure** – Since space and urban aesthetics will constrain equipment placement, system performance, and public acceptance, DC should include these factors in its technology system evaluation. For instance, a typical tolling system requires overhead mounted antennas to effectively read transponders, which may be visually intrusive, which may not be possible given federal and DC rules and requirements. Some technologies also require intensive high-bandwidth communications, which would require construction of communications infrastructure such as conduit banks and telecommunications hubs. However, some technologies can disseminate pricing and congestion information, potentially eliminating other electronic road signs.
6. **Cost** – DC should consider both the upfront capital cost of implementation and ongoing operational costs in evaluating the lifecycle costs for various pricing approaches.
7. **Market penetration and interoperability** – Widespread adoption of technologies in the region, such as EZ Pass for high-occupancy-toll (HOT) lanes and bridge tolls in Virginia and Maryland, would make implementation using this type of charging equipment and technology much more streamlined. However, EZ Pass and similarly established systems charge significant fees to access their technology and services. Other more complex payment structures needed for area pricing scenarios could build off existing methods between local and state municipalities and ride-hailing services.

8. **Scalability and flexibility** – DC should also consider the ability of the technology to support sophisticated business rules, such as charging or applying discounts by vehicle class, time of day, and/or location. Any selected technology should have the ability to scale up from a pilot program to a region-wide system.
9. **Privacy** – The use of electronic transponders, license plate readers, and enforcement cameras all present levels of privacy concerns to vehicle users, despite near-ubiquitous use of location-tracking smart phones. Existing tolling systems' legal framework protects some individual information and qualifies when it can and cannot be used; congestion pricing systems could extend similar legal language to their use of data. Cameras and license plate readers are generally more intrusive, but electronic transponders can sometimes replace those uses and ensure that only specific data elements are collected and/or transmitted.

Technologies and approaches for pricing scenarios introduced and described in the previous sections can be categorized into two main groups based on their similarities: tolling technologies and parking technologies.

Tolling Technologies

Applies to: Cordon Pricing, Area Pricing, Bridge Tolling, and Pass-Through Traffic Tolling

A number of the pricing tools can leverage technologies traditionally used for tolling because they share the need to identify a vehicle at a particular location to apply the appropriate price or enforcement consequence. Area and cordon pricing involve checking for vehicles entering and/or exiting an area; therefore, tolling equipment is placed on the edges of a pricing area or strategically distributed within a pricing area. Pricing tools based on charging specific vehicle types (i.e. fleet pricing or FHV pricing) can also use toll equipment to categorize vehicles within a zone or on the borders of a zones.

Since the introduction of electronic tolling in the 1980s, the tolling industry has made progressive advancements in Automatic Vehicle Identification (AVI) and Automatic License Plate Reader (ALPR) technologies, which identify vehicles without impeding traffic flow. Typically, AVI antennas mounted over roadways read transponders in vehicles to identify those with pre-paid toll accounts. ALPR cameras mounted overhead capture images of vehicle license plates to identify those without a transponder. The system can use the images to match a vehicle to a pre-paid account, send its owner a notice of penalty, or send post-paid invoices.

Several emerging technologies may augment and eventually replace these current AVI and ALPR technologies:

- **Cell phone apps** – Several companies are using cell phone apps to determine vehicle location and collect tolls. Apps send the toll and associated license plates number to the toll facility operator to reconcile with license plates captured by toll operators. Some firms also use Bluetooth-based technologies connected to their app to help identify the number of carpoolers for discounts and for occupancy enforcement. Although firms are promoting "virtual" toll points, toll operators will still need ALPR on the roadside to enforce payment from travelers without apps.

Some mobile apps can also pair with devices connected to vehicle On-Board Diagnostic (OBD)-II ports to get more accurate vehicle information and mileage. Cell phone apps can also provide travelers with pricing information and reduce the need for electronic signs.

- **Dedicated Short Range Communications (DSRC)** – The National Highway Traffic Safety Administration (NHTSA) proposes to federally mandate that vehicles manufactured after 2023 have built-in vehicle communications devices to "talk" to other vehicles and roadside equipment. DSRC could allow vehicles to communicate their locations and use on-board sensors to indicate the number of vehicle occupants. DSRC could change the need for travelers to obtain transponders. However, roadside equipment to support DSRC and ALPR cameras to enforce payment by vehicles without DSRC likely will still be needed. If the NHTSA rulemaking for DSRC requirements passes, this technology could be very useful to support a C/AV (Connected/ Autonomous Vehicle) Zone pricing concept. DSRC can also help vehicles receive and display pricing information to travelers and reduce the need for electronic pricing signs in the field.
- **5G LTE Wireless** – Like mobile phones, vehicle manufacturers are starting to build cellular communications capabilities into their vehicles. This technology could enable vehicles to transmit location information to self-identify and/or pay when they enter a pricing zone or tolled roadway. Similar to DSRC, roadside equipment and ALPR cameras likely would be needed to enforce and/or charge vehicles without 5G wireless communications. Wide adoption of 5G-enabled vehicles could boost support for a potential C/AV Zone pricing concept. 5G-equipped vehicles could receive and display pricing to travelers, thereby reducing the need for electronic pricing signs in the field.
- **Mobile License Plate Readers Improvement** – As video camera and automatic character recognition processing improve and prices are lowered, enforcement of payment and vehicle restrictions based on license plate captures could support distributed deployment of mobile ALPR. Instead of implementing tolling equipment at fixed locations, mobile ALPR systems can be mounted on roving vehicles and/or portable stations. For example, San Francisco Municipal Transportation Agency (Muni) currently mounts mobile ALPR on some transit buses to enforce illegal bus lane parking violations. The Georgia Department of Public Safety mounts mobile ALPR on police vehicles to identify potential carpool scofflaws on the I-85 Express Lanes in Atlanta. With mobile ALPR, Internet of Things (IOT) communications, and computing advancements, costly fixed-location infrastructure could be avoided. Another option that could be considered—albeit with privacy considerations as well—is the ability to leverage multiple sourcing of public video feeds for pricing enforcement.
- **Automated Vehicle Occupancy Detection (AVOD)** – For pricing programs such as express toll lanes with carpool discount rates, verification and enforcement of the number of occupants in vehicles has been challenging due to the need for police enforcement, limited field coverage, and the cost of enforcement. In recent years, multiple vendors have deployed camera vision systems to automatically identify vehicle occupants with greater confidence.

- **Autonomous Enforcement Drones** – With advancements in autonomous ground vehicle - and aerial drone[b] - capabilities, acceptability, reliability, and costs, potential new concepts for checking transponders, vehicle types, and license plates could become more practical and cost effective than fixed tolling equipment installations. However, drone technology is currently expressly forbidden within and around DC for security reasons, as noted.

Radio Frequency Identification (RFID) based DSRC operating in the 902-928 MHz band is the industry standard upon which every major toll facility including those used by E-ZPass Agencies throughout the metropolitan region (Virginia and Maryland) and 17 other states[23]. This requires placement of RFID antenna overhead every 6 ft, from lane centerlines, an industry best practice for vehicle to transponder to lane association. Essentially, this requires RFID-based technologies to use overhead gantries rather than roadside monitors. OBU's provide an RFID per equipped vehicle and would require roadside infrastructure – including antennas, controllers, poles, mounting hardware, etc. –to support the DSRC required by these OBUs. The additional implementation costs to support OBUs is based on the assumption that the OBUs would primarily be E-ZPass transponders (or equivalent).

Newer OBUs, which plug in to newer vehicles' on-board diagnostic (OBD-II) ports, can track travel distance and in some pilot tests also time and location. This technology has proven viable in recent tests investigating mileage-based user fees (MBUFs) for road users[24]. Those same tests have shown that OBU users report diminished privacy concerns after use. Location-based tracking could support a congestion pricing program, but the technology has not yet been widely tested.

New providers promise to integrate multiple sensor systems – cell phones, OBUs, on-road detectors, and others – to create a less infrastructure-intensive road pricing system. While this technology is being pilot tested in various settings, the ultimate costs, feasibility, and impacts remain unclear. Given this uncertainty, the cost estimates reported in later sections did not include the use of mobile apps or other non-RFID OBU's to support a pricing regime.

Whether operated by DC or a private third party, there are many advancements that can make administrative and record keeping systems more customer friendly. Website interfaces, apps, and artificial intelligence-powered Interactive Voice Recognition are technologies that supplement traditional staffed customer service centers. More advanced administrative and record keeping systems allow payment methods beyond credit cards or bank accounts, which helps accommodate unbanked customers. For example, there are payment networks that use kiosks located in grocery and convenience stores to make it easier for people to pay for their chargers and charges with cash and/or mobile phones.

To address privacy concerns, these administrative systems can isolate payments and accounts from traveler location information. For example, Oregon Department of Transportation's (ODOT) OreGo road user charge program isolates traveler trip information with third party vendors, and only charged amounts are reconciled with

[b] The DC area is comprised of restricted and prohibited airspace areas, which prohibit (without an authorized waiver) unmanned aircraft within a 15-mile radius of the designated 'inner ring'. These regulations could potentially limit autonomous enforcement of a DC area congestion pricing program (Federal Aviation Administration).

ODOT's financial system. Additionally, some toll agencies, such as the Georgia State Road and Tollway Authority, have developed accounts that only need license plate information, bypassing the need for driver information or other identifiers.

Some technologies allow for pilot testing in advance of deploying across an entire area or population of drivers. Notably, the cell phone app-based systems drawing data from multiple sensors can be pilot tested at smaller scales, for reportedly very low up-front costs. A well-constructed pilot testing scheme could evaluate the relative benefits of different approaches to pricing, including:

- cordon vs area-based
- multiple geographies
- finely tuned exceptions
- security and privacy
- integration with other tolling programs and devices
- linkages to parking, other road pricing, and/or other vehicle-related fees
- limiting startup costs including reviews and lag between start of implementation and revenue
- revenue retention and leakage and resulting credit worthiness

Parking Technologies

Parking technologies have progressed dramatically with the introduction of electronic payment systems. Advancements in vehicle detection, payment methods, traveler information, and enforcement have improved the customer experience and operations for both on-street and off-street parking.

The District of Columbia could expand its current demand-based parking pricing program to include a broader area and explore additional pricing approaches, such as progressive duration pricing. For on-street parking, DC is already using pay stations and a mobile payment app (ParkMobile) to make it easier for customers to pay for and track parking use. Both electronic payment methods could help DC support an additional parking price for congestion reduction.

Since DC already employs a demand-based parking pricing program within a small area of downtown DC, a parking pricing approach to congestion could leverage the existing infrastructure and methodology used for the pilot program. The downtown DC pilot project used an 'asset-lite' approach, which utilized parking space detectors to cover 50% of the pricing area and blended this data with other sources to set parking prices more dynamically and to communicate available parking spaces to reduce traffic caused by circling vehicles looking for parking. The pilot project used embedded pavement sensors to detect parking occupancy, as well as a variety of data inputs (payment, citations) and a round of video camera data for initial calibration of the data model. Radar technologies can also help monitor on-street parking availability but were not used for the ParkDC pilot.

There are also other parking technologies DC could use to enable an expansion of their dynamic parking pricing program:

- *DSRC* –the Federal Government may mandate that vehicles built after 2023 have 5.9 GHz networking capability, which could provide another tool for monitoring parking availability. With built-in vehicle communications, DC and other DSRC-equipped vehicles could broadcast parking space and pricing information to vehicle navigation systems in real time. The District of Columbia could also allow parking payments through DSRC once a vehicle is parked.
- *Parking information dissemination and analytics* – Although DC currently disseminates parking information through its web-based parking map and app, more private sector involvement in on-street parking could improve travelers' decision making and reduce the need for parking pricing signs. Several parking information service providers, such as TomTom, provide both parking information and predictive parking availability information. DC should continue to engage the private sector on ways to share parking pricing and availability data.

IMPLEMENTATION CONSIDERATIONS

Implementing any kind of new transportation technology in DC has a combination of typical and unique challenges. Congestion pricing technology is no different, and its status as an emerging policy tool in this country means that the technology challenges often receive less attention in the early phases of planning. However, DC's unique status and remarkable set of overlapping authorities mean that no analysis of feasibility can focus just on technology, as it must pay attention to the existing complex regulatory environment.

The scenarios under consideration can be subdivided into policy options that could be implemented completely inside of DC and those that would also require additional jurisdictional coordination outside of DC. Depending on the location and placement of equipment to implement the decongestion policy options, it is possible that all of the policy options could be implemented wholly inside of DC, while scenarios implemented across the Large Downtown study are would not fall into this category.

Technology and Infrastructure

A major potential impediment to implementation in DC will be restrictions on overhead structures including gantries, cameras, and wires. The nation's capital aims to preserve important viewsheds, essentially making such overhead structures impossible in or near the monumental core, and in many corridors outside that core. The next section discusses some of the regulatory bodies that enforce these requirements.

As described above, overhead gantries are the established technology for highway tolling, as well as many cordon-pricing implementations. Virginia uses such structures on I-395 (inbound as far as Boundary Channel Drive) and I-66 (inbound as far as SR 110), almost up to the DC border. If DC were to pursue tolling the bridges carrying those highways into DC, it could consider trying to use the existing gantries, or installing new ones within DC. Working with Virginia would involve adding a new tolling zone beyond the current end points, and possibly still require new hardware and associated gantries. Building new gantries within DC (which starts at the Virginia edge of the Potomac River) would require engagement and likely approval from the range of stakeholders described below. The viewshed from the DC border to important civic places including the Lincoln

and Jefferson Memorials may make locating new gantries on these facilities within DC unlikely.

Emerging vendor-created technologies that rely on a range of sensors, as discussed earlier, could reduce on-road infrastructure requirements significantly. Further development and study, perhaps including well-designed pilot tests, would help clarify the potential benefits as well as the cost tradeoffs involved.

Tolling, Commuter Taxes, and Home Rule

Tolling of major highway facilities is a familiar and growing practice in the DC region, notably in Virginia and perhaps soon in Maryland. Policymakers may have concerns that any tolling or other road pricing within DC could violate a longstanding prohibition against imposing what is often colloquially called a "commuter tax." However, this provision of the Home Rule Act of 1973, which allowed DC to have an elected Mayor and council for the first time, does not specifically reference transportation, and the term "commuter tax" can be misleading.

The Home Rule Act does expressly prohibit taxing non-resident income[25]. As a result, the three regional jurisdictions do have reciprocity so that none of them charge non-residents income tax[26]. Such a non-resident income tax, when used in other states, is also often informally called a "commuter tax."

However, the Home Rule Act does not say anything about charging drivers for driving in DC, or for entering DC. Drivers from any jurisdiction pay the same amount to park on DC streets. Drivers from any jurisdiction can be issued fines for parking, red-light, or speeding violations, among others. DC maintains a system of red-light and speed enforcement cameras which automatically assess fines for violations. Notably, the surrounding jurisdictions currently do not penalize drivers licensed there for non-payment of fines in DC. As of late 2020, the outstanding balance due to DC, including from DC drivers, amounted to some $440 million, 85% of which is owed by drivers licensed in Maryland or Virginia[27].

The Mayor of DC has been empowered by its Council to negotiate reciprocity in collections with the neighboring jurisdictions. Given the additional requirements that congestion pricing could impose, arrangements could be included in the same negotiations.

Regulatory and Review Considerations Within DC

For the DC government, DDOT has authority over the planning, design, construction, and maintenance of all transportation infrastructure and operations within DC. DDOT would be the lead agency for the implementation of any congestion policy and program. DDOT would be required to coordinate and work with the Federal Highway Administration (FHWA) to seek the authority to implement a congestion policy option. Exactly what sort of authority would be sought by DDOT would be dependent upon the policy option chosen for implementation. There would be initial consultation between DDOT and FHWA during subsequent planning work that would be more formalized during the project's National Environmental Policy Act (NEPA) review phase. Due to the historic nature of much of the land within DC, as well as its viewsheds, regulatory

authority and/or oversight by several other agencies is highly likely. The following organizations may require additional coordination and approval for projects within DC.

National Capital Planning Commission

The National Capital Planning Commission (NCPC) is a federal agency that reviews, provides guidance, or approves projects and plans on federal land that impact the National Capital Region (NCR). NCPC's jurisdiction is defined as the NCR, which is approximately 2,500 square miles and includes Washington DC, Montgomery County, Prince George's County, Arlington County, Fairfax County, Loudon County, Prince William County, and the cities of Alexandria, Falls Church, Fairfax, and Manassas. NCPS staff advises the Commission which meets monthly.

As stated by the NCPC, the Commission's approval authority, which might trigger their involvement for a congestion pricing policy, includes any project on federal land in DC and any project on DC-owned land within the Central Core Area.[c] NCPC also must approve any transfer of jurisdiction in Washington, DC between federal agencies and District agencies. The Commission has advisory authority for master plans for federal land in the NCR, projects on federal land in the NCR, and projects on DC-owned land in DC but outside the Central Area. Certain projects are exempt from NCPC review, but NCPC staff must confirm if a project is an exception during the pre-submission briefing process. Due to the location of the proposed congestion pricing study areas, NCPC should be notified and contacted throughout any congestion pricing program development, as they will likely require coordination and may have a degree of regulatory oversight.

National Park Service

The National Park Service (NPS) holds jurisdiction over multiple land areas within DC. Construction permits are required for performing any construction related activity on Park land which is not under an official construction contract with the NPS. Construction activities requiring permits include building of temporary or permanent structures or monuments, installation and/or upgrade of utilities, installation of temporary communications towers, installation of monitoring and security equipment such as surveillance cameras, and alarm systems, and constructing or upgrading of road and bridges. Construction permits are also required for any roadway, traffic lane, or sidewalk closures supporting projects, along with the use of construction fencing, man lifts, forklifts, and cranes.

Within the potential Cordon, Area and Pass-Through Traffic charging areas, there are numerous NPS sites. Coordination with the NPS would be required for any project activity occurring on NPS land. Sensor locations for either the Small or Large Downtown Study Areas could be chosen to avoid NPS sites, but NPS would still likely need to be consulted along with other affected property owners. Sensor locations for a Pass-Through charging area, if that area were to encompass the boundaries of DC, could not

[c] Generally stated as an area west to east from 15th Street NW to North Capitol Street and south to north from Pennsylvania Avenue NW to Florida Avenue NW

avoid NPS sites as the Suitland Parkway, Clara Barton Parkway, Rock Creek Parkway, and similar arterials that cross the DC boundary are NPS facilities.

DC State Historic Preservation Office (SHPO)

Consultation with DC SHPO is required as a congestion pricing program would relate to aesthetics, viewsheds, and historic sites within DC. The DC SHPO aims to ensure that any work done on historic properties is compatible with the existing historic character.

Projects are either reviewed by the HPO or the Historic Preservation Review Board (HPRB) depending on the project's size, complexity, or if the HPO is not delegated for HPO approval. The planning and preparation costs associated with documentation and approval will depend on which board is assigned to review the program and its potential impacts to historic properties.

US Commission of Fine Arts (CFA)

The US Commission of Fine Arts (CFA) is an independent federal agency tasked with reviewing projects in DC with respect to design an aesthetics. Federal and DC agencies are required to submit for approval by CFA if they are planning or renovating buildings, parks, or Metro stations or proposing major new public infrastructure, such as a bridge, or modifying the streetscape design of a public street.

The implementation of a congestion pricing program would most likely require review by CFA due to the proposed structures and tolling mechanisms needed along certain boundary points of the charging area. It should be noted that CFA has restricted, with few exceptions, the use of full-span mast arms for traffic equipment and signage within DC. This should be an implementation consideration for any policy option involving the installation of equipment overhead, which could apply to the Cordon Pricing, Area Pricing, or Pass-Through Traffic Tolling Scenarios. A camera-based implementation of any of those scenarios could avoid overhead equipment, instead relying on existing or additional poles currently used for traffic signals and cameras for other purposes.

Architect of the Capitol

Another federal agency, the Architect of the Capitol, is responsible for the development, operations, maintenance, and preservation of the US Capitol Complex, including Capitol Hill. While the proposed Cordon, Area and Through Traffic Zone boundaries do not impact Capitol Hill, there are buildings such as the John Adams Building, which are under the jurisdiction of the Architect of the Capitol and are immediately adjacent to the proposed boundaries and may require coordination. Depending on the location of and associated construction of pricing equipment, the Architect of the Capitol may also have some regulatory oversight.

Congress

Congress will play a regulatory and/or oversight role over the implementation of a congestion pricing program inside of DC. Any DC law may be reviewed by the Congress, which may enact a joint resolution disapproving the action[28]. At the time of this publication the exact nature and significance of that role is unknown and may change in the coming year(s). Regardless, congressional concerns will have to be addressed as

part of any program implementation. In particular, the delegation of representatives from surrounding jurisdictions will have considerable sway over the potential implementation of congestion pricing.

Additional Implementation Considerations Outside of DC

The Large Downtown study area for Cordon and Area pricing scenarios, as well as any Through Traffic scenarios, would have additional jurisdictional and regulatory issues. The Large Downtown boundary extends across the Potomac River into Arlington, VA. It includes major commercial and historically significant areas, such as Arlington National Cemetery, the Pentagon, parts of Rosslyn, and National Landing. Policy options with this larger boundary would require coordination with Arlington County and the Commonwealth of Virginia. In addition to coordination with Arlington County and the Commonwealth of Virginia, other local and federal governing bodies may need to be involved in project coordination and approval.

Commonwealth of Virginia

Any pricing scheme involving hardware and pricing within Virginia will require engagement with elected and departmental leadership at the state level. DC would need to engage the Virginia governor and legislature, Virginia Department of Transportation (VDOT), and likely the Commonwealth Transportation Board. That said, Virginia does have a track record of successfully implementing dynamic pricing in several regions, including I-395 and I-66 HOT lanes in Northern Virginia.

The Northern Virginia Transportation Authority and Northern Virginia Transportation Commission also each have jurisdiction within Northern Virginia and would need to be consulted as key stakeholders early in the development of any pricing alternative including that region.

Arlington County

Arlington County business districts and residential neighborhoods sit directly across the Potomac River from downtown DC, southwest DC, and Georgetown. Implementing a version of the large study area that includes Rosslyn and National Landing (Crystal City and Pentagon City) would require close collaboration with County elected officials, government departments including Environmental Services (which includes transportation), along with other Virginia stakeholders. Arlington County controls its surface streets, except those state routes controlled by VDOT. For a cordon that would include part of all of the Rosslyn and National Landing areas, hardware would likely need to be installed on Arlington streets.

Arlington National Cemetery

The Large Downtown boundary includes Arlington National Cemetery, which is under the jurisdiction of the Department of the Army. Specifically, the US Army Corps of Engineers is responsible for the facility and infrastructure of Arlington National Cemetery. Arlington National Cemetery holds 27-30 funeral services a day Monday-Friday, and 6-8 services on Saturdays. In 2014, NPS announced that the Arlington National Cemetery Historic District was added to the National Register of Historic

Places. Any plans for properties listed on the National Register require consideration of Section 106 of the National Historic Preservation Act of 1966. On projects such as the Arlington National Cemetery Southern Expansion and Roadway Realignment, coordination was required between Arlington National Cemetery, the FHWA, Arlington County, and the Virginia Department of Transportation (VDOT). Additionally, in 2010, Arlington National Cemetery established an Advisory Committee on Arlington National Cemetery, who is responsible for providing the Secretary of Defense advice and recommendations regarding the administration of Arlington National Cemetery, the erection of memorials at the cemetery, and any master planning of the cemetery. Questions may arise as to how those traveling to and from Arlington National Cemetery for funeral services may be impacted by a congestion pricing program.

DEVELOPMENT AND CALIBRATION OF ANALYTIC MODEL

To analyze the various pricing approaches described above, the consultant team adapted an elasticity-based economic model originally developed for similar use in New York City. The Balanced Transportation Analyzer (BTA) is a Microsoft Excel-based traffic and financial analysis tool that estimates prospective benefits and costs of urban congestion pricing. This transportation model, built by economist Charles Komanoff, has already been modified for use in Seattle and other cities exploring congestion pricing. At the outset of the project, the study team and steering committee identified this model as a useful tool to explore initial findings around congestion pricing alternatives for DC and its region. This user-friendly tool lays out the range of potential impacts of different road pricing scenarios which can help guide decision-makers on the selection of specific approaches.

Background on the BTA

Economist and policy analyst Charles Komanoff first began developing the BTA in 2007 to determine whether a congestion charge on vehicles entering New York City's CBD could generate enough revenue to fully fund mass transit and eliminate fares. His initial work on the model coincided with the effort by then New York City Mayor Michael Bloomberg to enact a congestion pricing plan for Manhattan. Over the next dozen years, the model grew to include dozens of spreadsheet tabs with inputs touching on virtually every mode of travel to and from Manhattan. The model also incorporated scores of feedback loops, such as motorists' tendency to drive more as congestion dissipates, along with their propensity to drive less as transit service is improved due to investing congestion revenues in system enhancements. The model permits users to test a range of pricing schemes (e.g., fixed fee, variations by time of day/distance traveled, one-way or two-way) for their impacts on traffic volumes, travel speeds and times, and revenue. While Mr. Komanoff continued to evolve the model, he also made it publicly available for use in other circumstances.

BTA Applications

The primary function of the BTA model is to provide a cost-benefit evaluation of alternative congestion pricing proposals. It does this by estimating key outputs including toll revenues, changes in motor vehicle speeds within the pricing zone and on the "approaches," and changes in both vehicle miles traveled (VMT) and transit ridership.

The model also reports societal benefits such as the monetary value of fewer crashes, cleaner air resulting from reduced driving, and health benefits from more biking and walking, while accounting for the cost of administering the pricing system and the value of travelers' convenience that is lost as drivers shift to other modes. The model also lets users evaluate and optimize a range of pricing schemes (flat fee vs. variable pricing throughout the day and on weekends and holidays), different pricing tools (cordon, area toll, or a mix), and multiple pricing area geographies, all rendered in a single, comprehensive output table.

Comparison of the BTA with Traditional Travel Demand Models

The BTA differs in several ways from traditional macroscopic travel demand models (such as TransCAD, PTV Visum, or CUBE) that are often used to assess the impacts of roadway pricing and transportation dynamics on a city or regional level:

- The BTA is focused on monetary and societal impacts from pricing measures, rather than specific traffic and mode changes, and it is built to examine how these factors intertwine with transportation policies.
- The model's dynamic nature incorporates overall changes in trips resulting from pricing changes, rather than solely mode or temporal changes.
- The Excel-based platform employed by the BTA allows it to be accessed and manipulated by a broader audience than trained traffic modelers; it also reports its results instantly, allowing quick optimization of proposed policies.

In short, the BTA is a tool that lets decision-makers quickly and easily evaluate the cost-benefit variances between different pricing schemes, on a broad geographic scale. If decisions are made to proceed further with a pricing system based on the BTA results, a following step would be to analyze a chosen plan in a macroscopic model that can evaluate additional metrics using the model's outputs as a starting point. For example, while the BTA estimates overall change in VMT to a large area, a macroscopic model could then be used to identify changes on specific roadways and their individual origin-destination travel times. For additional detail on the BTA, please see Appendix B.

Application of the BTA to DC

The BTA was uniquely suited for this study of congestion pricing in DC because it enables a relatively quick and transparent analysis of the overall costs and benefits of such a system in the city and region, including the estimated expenditures required to implement congestion pricing, the magnitude of the likely revenues (much of which could be invested in the transit system), and the city-wide reduction in traffic (measured by both reduced VMT and increased vehicle speeds). These outputs enable project stakeholders to make decisions on the viability and equity impacts of any individual pricing policy and determine which, if any, to move forward into more detailed study.

The BTA model version developed for DC has been set up to serve as an ongoing resource for DCST, DDOT, and other stakeholders, who will be able to easily adjust key inputs in the model to test different pricing schemes and quickly identify their effect on implementation costs, toll revenues, vehicle emissions and other factors.

Baseline Data of the Study Areas

Once calibrated for DC, the BTA provides a simplified breakdown of trips by mode for each study area: the Small Downtown study area, the Large Downtown study area, and the DC-wide study area. These baseline numbers are used to evaluate how each congestion pricing scenario changes trip volume and type. Data used to calibrate the BTA for use in DC are listed and described in Appendix B. The BTA model estimates that 1,088,400 people enter the Small Downtown study area daily by all modes. Of those roughly one million persons, 710,800 enter the area in 415,770 vehicles.

Vehicles by this definition include trucks, automobiles, and for-hire-vehicles (FHVs) – all of which may be charged under a congestion pricing scenario. Data for the Small Downtown study area as well as the Large Downtown and DC-Wide Study Areas are shown in Figure 31 below.

Figure 31 Study Area Daily Entries

Study Area	Vehicles Entering	Persons Entering in Vehicles	Persons Entering by All Modes
Small Downtown	415,137	710,800	1,088,400
Large Downtown	588,048	955,500	1,420,100
DC-Wide (all of DC)	672,747	855,000	1,590,800

The mode split of all persons entering or travelling through the Small and Large Downtown Study Area and the DC-wide Study Area is shown in Figure 32 below. Over one-quarter of all persons entering the small downtown study area travel by transit, while close to 60% enter by automobile for either work, commercial, or non-work purposes. The BTA does not consider walking trips separately because the model focuses on entries into the study areas, not trips within the study areas. While many walking trips occur within the study areas, the number crossing the study area boundaries should be marginal. Also, when considering mode shift of automobile travelers with longer commutes, the primary changes would be to carpool, transit, or bicycling, given long average trip lengths.

Figure 32 Study Area Daily Entries by Mode

Mode	Automobile		Other Vehicles		Transit			Active Modes
Study Area	Auto work & commercial	Auto non-work	FHV	Truck	Metrorail	Metrobus & Circulator	Commuter Bus & Rail	Bicycle
Small Downtown Study Area	245,100	375,000	70,900	19,800	274,400	53,100	23,600	26,500
Large Downtown Study Area	474,900	385,800	67,700	27,100	329,100	72,100	28,800	34,600
DC Wide Study Area *(all of DC)*	453,800	332,700	41,800	26,700	394,300	278,300	24,400	38,800

SECTION 4: PRICING SCENARIOS AND RESULTS

This section describes and analyzes specific congestion pricing scenarios with further refined tools, strategies, and parameters for charging, including when charges would apply, how much those charges are, and who is required to pay.

The following subsections present analysis for ten scenarios: Scenarios 1-3 – each applied to both the Small and Large Downtown Study Areas – comprise six scenarios of cordon-based congestion pricing. Scenario 6 is also applied to both downtown study areas. Scenarios 4 and 5 each consider a single concept, tolling already tolled bridges, and charging pass-through trips, respectively. Later subsections assess refinements to those scenarios. in terms of the impacts of time of day and price refinements, exemptions, and reinvested revenue.

Scenarios 1, 2, and 3 have key elements in common: they price entry into a defined, enclosed area, and each of those scenarios is analyzed for the Small Downtown and Large Downtown Study Areas (the geographic extents of which are defined in Section 3). Scenario 4 applies tolls to specific bridges over the Potomac, and Scenario 5 charges trips that pass through DC. Each is analyzed using the BTA. Scenario 6 examines the potential impacts of increased prices for on-street parking, which could occur independently of, or in conjunction with, other scenarios.

MAIN SCENARIOS: DEFINED PARAMETERS

Scenarios 1, 2, and 3 all rely on the defined cordons (Small and Large Downtown Study Area) and thus are appropriate for direct analysis using the BTA. Scenarios 4 & 5 are also analyzed using the BTA, although certain assumptions are made given that neither is a cordon-based pricing scheme. Scenario 6 is analyzed using other methods, as on-street pricing is not a cordon-based pricing scheme and would likely be used in conjunction with other congestion-reduction measures.

The main charging times were set between 6 am and 10 am for weekdays and 8 am to 8 pm on weekends, with variations to allow for differences in the structure of each scenario. The weekday peak period is set to include “shoulder” or peak-adjacent hours, to encourage shifts in travel mode as well as time of day. To reflect lower congestion and perceived lower willingness to pay on weekends, the charge is half the weekday charge. No charges apply outside of the specified time periods. The charges were scaled to be comparable to existing bridge and road tolls in the region; the study team also analyzed the levels of existing congestion prices in major international cities. After an initial analysis of scenarios with lower fees, the charges were increased at the guidance of the steering committee.

Each main scenario is summarized in Figure 33 and then fully described below.

Figure 33 Congestion Pricing Scenario Parameters

Scenario	Description	Study Area	Time of Charges	Charge Details
(1)	Cordon (Inbound): inbound-only charges, weekday am peak only	Small (1.S) & Large (1.L) Downtown Study Areas	Weekday morning peak (6am-10am) Weekend all day (8am-8pm)	$10 Flat fee for entry (weekday) $5 Flat fee for entry (weekend)
(2)	Cordon (Inbound/ Outbound): inbound and outbound charges, weekday am and pm peak	Small (2.S) & Large (2.L) Downtown Study Areas	Weekday peaks (6am-10am & 4pm-8pm) Weekend all day (8am-8pm)	$5 Flat fee for entry or exit (weekday) $2.50 Flat fee for entry or exit (weekend)
(3)	Area Pricing (per minute with Cordon Inbound option): per minute charges while travelling with option for Cordon inbound-only charge, weekday am peak only	Small (3.S) & Large (3.L) Downtown Study Areas	Weekday morning peak (6am-10am) Weekend all day (8am-8pm)	50% of automobiles and trucks, 100% of FHVs: $0.60 charge per minute while driving in charging area (weekday) $0.30 charge per minute while driving in charging area (weekend) 50% of automobiles and trucks: $10 Flat fee for entry (weekday) $5 (weekend) for entry (weekday)
(4)	Bridge Tolling: inbound charge, weekday am peak only	I-66 & I-395 Express lane traffic only	Weekday morning peak (6am-10am) Weekend all day (8am-8pm)	$10 Flat fee for entry (weekday) $5 Flat fee for entry (weekend)
(5)	Pass-through Traffic Tolling	Through-traffic only (throughout DC)	Weekday morning peak (6am-10am) Weekend all day (8am-8pm)	$10 Flat fee for entry (weekday) $5 Flat fee for entry (weekend)
(6)	On-street Parking Pricing	Small & Large Downtown Study Areas	Weekday & Weekends all day (24 hours)	$3.55/hour on-street parking price (54% increase from $2.30)

Scenarios 1 & 2: Cordon Pricing (two types)

Scenarios 1 & 2 charge drivers for crossing a cordon, defined by the Small and Large Downtown areas described in Section 3. Scenario 1, the "Inbound" scenario, charges a toll of $10 for crossing into the cordon area during the am peak times and $5 during weekend charging period. Scenario 2, the "Inbound/Outbound" scenario, charges for crossing the cordon in *either* direction during both the am and pm peak times and the same time period over the weekend as Scenario 1. Because a typical commuter trip would enter in the am and exit in the pm, a toll of $5 is charged for each crossing during weekday peaks and $2.50 during weekends (half the charge price of Scenario 1), to keep the overall charging level equal.

Scenario 1 is similar to congestion charging schemes implemented in several European cities and under consideration in New York, Seattle, and other North American cities. Scenario 2 allows for more flexible charging, which could help to shift trips to other times of day as well as charging less for people who might, for example, arrive on transit in the morning but depart via FHV in the afternoon or evening. However, Scenario 2 requires higher capital and operating costs, as an outbound charge would require twice the number of cameras at entry/exit points. Scenario 2 also requires more complicated modeling of trip-making behavior.

Scenario 3: Area Pricing

Scenario 3 applies a charge to time spent driving within the cordon area, analyzed for both the Small and Large Downtown Study Areas. Although area pricing can charge either by time spent driving or distance driven within the cordon, this study only analyzed an area pricing scenario for time spent travelling. The BTA assumes that driving within the cordon happens at the average speed calculated during model calibration (described in Section 3) and the results for charging by time will be proportional to charging for distance. Additionally, given current and likely near-term technology, charging for the time spent within the cordon is more straightforward, as it could rely on the same technology as the cordon-crossing charges described in Scenarios 1 & 2.

Charging for distance driven within the cordon could support policy goals of limiting driving, but this approach would not necessarily limit trips entering within key peak periods. Charging only for the time actually driving within the cordon, rather than all time spent within the cordon, could lower congestion charges for drivers entering during the peak, presumably offset by charges for parking. However, that would require OBUs capable of recording and reporting when a vehicle is being driven, and distinguishing that from, for example, idle time while making deliveries.

While this scenario assesses the impacts of a time-based charge, the results at this level of analysis are likely to roughly mimic those of a distance-based approach. Time spent or distance driven within the cordon are proportional, given the model's assumption of constant average speed across each study area.

From an equipment standpoint, a per minute charge can be monitored with the same cameras as a cordon scenario. As this approach would require additional processes to monitor a vehicle's time spent within the cordon area, operating costs would be higher for Scenario 3 than Scenario 1. Using OBUs instead of cameras for area pricing charges would require roadway sensors to read/write to the OBUs and result in even higher

operating costs. The OBU sensors are typically mounted on overhead gantries, which is likely not possible within DC due to viewshed regulations.

Scenario 3 analyzes a hybrid approach, with half of all vehicles charged a cordon entry charge and the other half charged for every minute driven within the cordon area during the charged time period. This hybrid approach was selected because it is assumed that some vehicles entering the cordon would opt out of the area pricing approach – either because of privacy concerns, lack of an OBU, or preference for a flat fee. While the specific split of drivers choosing each charging method could vary, modeling an even split should provide reasonable insight into the performance of this policy. For vehicles opting into the area pricing approach, this scenario applies a $0.60/minute charge during weekday AM peak to 50% of cars, trucks, and FHVs; and a $0.30/minute charge on weekends. The other 50% of entering vehicles (those opting out of the timed approach) would be subject to the same cordon crossing charge as in Scenario 1 –$10 during weekday am peak and $5 on weekends.

The $0.60/minute charge was set by estimating the cost of a trip from the cordon boundary to its center during the am peak hours. The goal was for that trip to cost just less than $10 to incentivize regular driving commuters to opt into the timed-based pricing option.

Scenario 4: Bridge Tolling

Scenario 4 essentially functions as a cordon area charge for vehicles that enter DC from I-66 and I-395 Express Lanes. According to traffic volume data from 2018, 235,000 vehicles, 16.9% of all vehicular traffic entering DC, travel on I-66 and I-395 Express lanes daily. Unlike in Scenarios 1-3, all vehicles entering DC on these roadways will be charged – even if they are accessing areas outside of downtown. Vehicles are charged a flat fee of $10 on weekdays during am peak hours and $5 on weekends. Because this charge only occurs on I-66 and I-396 Express lanes, an estimated 113,700 vehicles are charged daily, while over 415,000 vehicles are charged daily in Scenarios 1-3 for entering the Small Downtown Study Area.

Scenario 5: Pass-Through Traffic Tolling

Scenario 5 charges vehicles that use roadways within DC as a through-route to travel between parts of Maryland and Virginia; vehicles that remain on major interstates when travelling through DC are not charged. As much as 37.6% of all trips occurring within DC originate outside and end outside of DC[29]. Conservatively it is estimated that because a portion of these trips remain on the interstate, 25% of all daily trips on DC's road network is from pass-through traffic. Scenario 5 charges pass-through traffic (25% of all vehicle trips) within DC a $10 flat fee on weekdays during am peak hours and a $5 flat fee charge on weekends. An estimated 168,200 vehicles are charged daily in this scenario. This scenario requires tolling equipment to be located along major roadways entering and exiting DC to monitor vehicle entries/exits.

Scenario 6: On-Street Parking Pricing

Scenario 6 considers the potential impact of significant increases in the cost of parking in downtown DC. While this cannot be modeled using the BTA (see Appendix B), local and national experience with parking pricing, and particularly dynamically priced parking,

offers some guidance. Much of the parking in downtown DC, especially parking for peak-period commuters, is in off-street garages. This supply is almost entirely controlled by either the private sector or the federal government. While DC imposes certain taxes on the private supply, it does not have direct control over prices charged. It does however control most on-street parking.

In order to test a simple change to parking pricing, this scenario assumes an across-the-board parking price increase rather than the more nuanced demand-based pricing used in DC's parking pricing pilot. While workers do not park on-street for a full workday in most cases (meters have two hour limits in the area), this scenario considers increasing the price of on-street parking by $10 over an 8-hour time period, comporting with the $10 congestion pricing charge used in Scenarios 1 through 5. The current on-street parking rate in DC citywide is $2.30 per hour[30], as established in the Fiscal Year 2016 Budget Support Act[31]. Increasing that base rate to $3.55 per hour achieves the target $10 increase.

MAIN SCENARIOS: IMPLEMENTATION COSTS

The scenarios chosen for study encompass varying geographies and require varying equipment and processing systems. Cost estimates based on detailed workups were developed for implementation of a cordon pricing system for both the Small and Large Downtown Study Areas (Scenarios 1), as well as the Bridge Tolling scenario (Scenario 4). Costs for Scenarios 2 and 3 were developed by factoring up the costs that a more complex cordon-pricing or area-pricing program would have on Scenario 1. Cost estimates were not developed for Scenarios 5 or 6.

Costs for each scenario are split into capital, lifecycle, and operational expense. All basic cordon pricing programs should assume a 25% cost per vehicle transaction for operating expenses, which include administrative costs for transaction processing, customer service, revenue collection, and other management needs. Capital expenses – which include roadside components (and any necessary civil infrastructure for gantry, signs, sign structures, equipment pads, cabinets, power/communication cabling), tolling equipment, project management, and administrative costs – and lifecycle costs vary based on the size of the study area and the necessary number of detection points for each cordon.

Total capital expenses for Scenario 1.S are estimated at $16.5 million. Total capital expenses for Scenario 1.L, with almost 30 more detection points, are estimated at $19.5 million. Annualized lifecycle costs are estimated at $3.5 million for Scenario 1.S and $4.3 million for Scenario 1.L.

Scenario 2's capital expenses are higher than Scenario 1, as each detection point would have to be equipped with cameras tracking vehicles leaving as well as entering the cordon area. Scenario 2 would incur 1.8 times the capital and annual maintenance costs of Scenario 1, due to the increase in the number of cameras installed. Capital costs would be $29.7 million and $35.1 million for the Small and Large Downtown Study Areas, respectively.

Scenario 3, with its hybrid approach involving both cordon and area pricing charges, would cost more than Scenarios 1 or 2. Using OBUs to monitor vehicles' time within the cordon area requires equipment to read and write to the OBU and sophisticated back-

end systems to process data. Total capital and maintenance costs would be $41.3 million and $48.8 million for the Small and Large Downtown Study Areas respectively, roughly 2.5 times those of Scenario 1, while operational costs would be 1.6 times those of Scenario 1. If Scenario 3 were implemented solely with two-way cameras at the cordon, capital and maintenance costs would be similar to those of Scenario 2 ($29.7 million for the Small Downtown Study Area and $35.1 million for the Large Downtown Study Area) but with higher operating expenses (1.2 x the assumed 25% per transaction) due to the more complicated transactions of an area pricing program.

Cross-jurisdictional enforcement is necessary for congestion pricing scenarios in the Large Downtown Study Area (for Scenarios 1, 2, and 3) and Scenario 4. Its success depends on negotiated agreements that do not currently exist. Success will also be influenced by the choice of technology. Implementation that relies solely on cameras may encounter similar challenges to DC's speed- and red light-camera enforcement – drivers from other jurisdictions simply ignore mailed citations or bills. These considerations may point to the need for a system featuring both cameras and OBUs, which will be more expensive. On the other hand, such a system could make it more efficient to manage exemptions or discount programs.

Figure 34 summarizes cost estimates for Scenarios 1-4. A line-item cost estimate was not developed for the Scenario 5 or Scenario 6.

Figure 34 Estimated Capital Expenses, Lifecycle Costs, and Operating Expenses: Scenarios 1-4

Scenario, Study Area	*Installation of Roadside Components* (a)	*Other Setup Costs* (b)	Total Capital Expenses (c)	Annualized Lifecycle Expenses (d)	Operating Expenses (% of gross Revenue) (e)
Small Downtown Study Area (estimated 80 detection points)					
(1.S) Cordon (Inbound)	*$8.9 M*	*$7.6 M*	$16.5 M	$3.5 M	25%
(2.S) Cordon (Inbound/ Outbound)	*$16.0 M*	*$13.7 M*	$29.7 M	$6.3 M	25%
(3.S) *Cameras only, No OBUs* Area Pricing (per minute with Cordon Inbound option)	*$16.0 M*	*$13.7 M*	$29.7 M	$6.3 M	30%
(3.S) *OBU roadway sensors* Area Pricing (per minute with Cordon Inbound option)	*$22.3 M*	*$19 M*	$41.3 M	$8.7 M	40%
Large Downtown Study Area (estimated 107 detection points)					
(1.L) Cordon (Inbound)	*$11.9 M*	*$7.6 M*	$19.5 M	$4.3 M	25%
(2.L) Cordon (Inbound/ Outbound)	*$21.4 M*	*$13.7 M*	$35.1 M	$7.7 M	25%
(3.L) *Cameras only, No OBUs* Area Pricing (per minute with Cordon Inbound option)	*$21.4 M*	*$13.7 M*	$35.1 M	$7.7 M	30%

Scenario, Study Area	*Installation of Roadside Components* (a)	*Other Setup Costs* (b)	Total Capital Expenses (c)	Annualized Lifecycle Expenses (d)	Operating Expenses (% of gross Revenue) (e)
(3.L) *OBU roadway sensors* Area Pricing (per minute with Cordon Inbound option)	*$29.8 M*	*$19 M*	$48.8 M	$10.7 M	40%
Bridge Tolling Scenario (4 detection points)					
(4) Bridge Tolling (f)	*$9.6 M*	*$7.6 M*	$17.2 M	$3.0 M	25%

(a) Detection points and/or roadside component installation costs include signage, civil infrastructure (if needed), and equipment including dual ALPR cameras, illuminator, controller, and mounting apparatus.

(b) Other Setup Costs include project management (integration/oversight/testing) and administrative/host (hardware and software including disaster recovery) costs.

(c) Capital Expenses are the Installation Costs combined with Other Setup Costs.

(d) Annualized Lifecycle Expenses include regular maintenance costs (regular monthly preventative maintenance checks/service: labor (field technician) and materials (tools, vehicle) X number of detection points)) and major maintenance costs (replacement/refreshment on a 7-year cycle: labor and materials (to remove/replace/configure/test, including tools, vehicle, specialty equipment X number of detection points X 1/7 (replacement cycle)).

(e) Operating expenses include administrative costs to process transactions, collect revenue, and provide customer service, as well as management/oversight costs. An estimate 25% of each vehicle transaction is needed for operational costs.

(f) Tolling is a capital-intensive endeavor due to the amount of infrastructure required for each toll zone which drives up the cost. This report assumes a single toll zone in each direction of travel, each using dual gantries, two in each direction of travel, to achieve an accurate reading. It also considers the equipment needed for various subsystems required including: automated vehicle detection, license plate reading, digital video audit, communications, and power generation.

MAIN SCENARIOS: ANALYSIS RESULTS

Scenarios 1-5: Measures of Effectiveness

Scenarios 1 through 5 were analyzed using the BTA and related methods. The BTA results provide insight into how well each approach performs relative to the goals described in Section 1. Specifically, the BTA produces measures of effectiveness that address the direct impacts of congestion pricing – changes in travel speeds, volumes, mode shares – as well as the key indirect impacts of primary interest – revenues and societal benefits.

Each of these measures of effectiveness is described below. In all cases, the baseline represents current (2017-2019) travel volumes and traffic conditions.

Average Change in Area Speeds: the change in average vehicle speed for a typical weekday (24-hours) within the pricing zone, compared to the baseline. Speeds within the pricing zone are calculated through an algorithm that is based on a combination of vehicle volumes (work trips, non-work trips, through trips, FHV's, trucks, and buses) and trip distances for inbound, outbound, and intra-pricing zone trips. Speed calculations account for the "rebound effect," wherein implementation of a pricing scheme reduces traffic volume, which then attracts additional vehicles until the network reaches a new equilibrium. More detailed (hour by hour) speed changes are provided in the model

itself.[32] It is not the goal of congestion pricing to increase average speeds to above a safe speed limit, however, the average speed within both downtown study areas for DC are much lower than the speed limit itself.

Annual Gross and Net Revenue: the estimated total annual revenue that would be generated by the selected pricing scenario, including fees from vehicle congestion charges and transit fares from additional riders. For cordon pricing scenarios, vehicle charge revenues are based on total vehicle trips, while the time-based scenario is calculated based on vehicle travel times[33]. The BTA provides an output for Annual Net Revenue, which subtracts estimated administrative costs (capital expenditures and operating costs). However, the results provided in Figure 35 show generated gross revenue, as more refined estimates of capital expenditures and annual operating costs are provided in the sub-section, 'Main Scenarios: Implementation Costs and Considerations' above.

Change in Volume of Vehicle Trips: the average daily change (weekdays and weekends) in vehicle trips travelling into the pricing area. The output is represented as both the average percent change compared to the total vehicle trips that entered the area under the baseline condition, and as the actual number of trips eliminated daily. The number of trip reductions vary between weekday and weekend, so both numbers are provided in the results table. Larger study areas require higher trip reduction totals to impact the percentage change in trips.

Change in Volume of People Trips: the average weekday change in total person trips travelling into the pricing area. Trip calculations account for all travel, including increases in transit and bicycle travel and reductions in vehicle travel. This metric is represented both as a percent change and as an actual number change. The BTA does not identify pedestrian travel separately due to its focus on larger geographies and longer trips.

Daily Traveler Time Savings: the total hours number represents the average daily change (weekdays and weekends) in overall person hours spent travelling, in all modes. This is based on reductions in congestion and subsequent reductions in travel time, for bus riders and drivers, both within and outside of the pricing area. Hours annually applies this hourly time savings across all bus riders and drivers within the cordon area for an entire year.

Annual Net Income: the Annual Net Revenue, minus any dedicated spending (reinvested revenue) and allocations (charging exemptions) tied to the pricing scenario. This is used to determine if the pricing scenario spends more money than it is raises. Allocations could include dedicated revenue investments in transit system improvements, service enhancements, and fare subsidies. Allocations for transit investments, and net income totals, are discussed under 'Refined Scenarios and Analysis Results' below.

Annual Societal Net Benefit: the estimated societal benefits of the selected congestion pricing scenario. These include estimates of revenue lost due to decreased parking demand, as well as various "soft" costs, such as time savings for travelers, reduced fossil fuel usage and environmental impacts, and health benefits of increased walking and cycling. For these "soft" costs, monetary values have been assigned based on various research studies and consultant team estimates.

Scenarios 1-5: Model Results

Figure 35 summarizes the results from applying the BTA to evaluate Scenarios 1, 2, and 3, for each of the Small Downtown and Large Downtown Study Areas.

Figure 35 Model Results from Congestion Pricing Scenarios 1-3

Scenario, Study Area	Average weekday speed (within 24 hr period) in charged area; % change	Annual Gross Revenue	Change in volume of vehicle trips into priced area: % change	Change in # of people entering priced area on a weekday; % change	Daily Traveler time Savings: total hours; hours per person annually
Small Downtown Study Area					
Baseline (No charge)	12.5 mph average weekday speed; 710,800 total vehicle trips into priced area; 1,088,400 total trips into priced area by all modes				
(1.S) Cordon (Inbound)	19% 14.9 mph	$345 M	-7% -29,422 weekday; -12,793 weekend	-0.7% -7,100	40,800 total; 20 per person per year
(2.S) Cordon (Inbound/ Outbound)	23% 15.4 mph	$440 M	-10% -42,839 weekday; -12,714 weekend	-0.3% -2,800	50,400 total; 24 per person per year
(3.S) Area Pricing (per minute with Cordon Inbound option)	24% 15.6 mph	$355 M	-7% -28,819 weekday; -9,799 weekend	-0.2% -1,700	49,800 total; 24 per person per year
Large Downtown Study Area					
Baseline (No charge)	14.6 mph average weekday speed; 955,500 total vehicle trips into priced area; 1,420,100 total trips into priced area by all modes				
(1.L) Cordon (Inbound)	14% 16.8 mph	$514 M	-8% -43,307 weekday; -26,578 weekend	-0.6% -9,000	48,700 total; 18 per person per year
(2.L) Cordon (Inbound/ Outbound)	18% 17.2 mph	$667 M	-11% -64,252 weekday; -26,451 weekend	-0.5% -7,100	62,200 total; 22 per person per year
(3.L) Area Pricing (per minute with Cordon Inbound option)	18% 17.2 mph	$524 M	-8% -44,837 weekday; -22,914 weekend	-0.2% -3,200	58,700 total; 21 per person per year

While each of these results is presented and discussed as a specific estimate, they together should be considered as just that – *estimates* – and treated as midpoints of necessarily large ranges at this level of analysis.

Taking Scenario 1.S as the base for comparison, its modeled results are substantial. Speeds improve by nearly 20%, a result of nearly 30,000 (7%) fewer vehicle trips on a typical weekday. Although vehicle trips decline by 30,000, the number of person trips decline only by 7,000 people, indicating that most people will not be altogether deterred from entering the cordon area but will instead change modes or carpool to avoid congestion charges. The result is a travel time savings of over 40,000 person-hours, time that can be spent doing more productive things than traveling. The system generates $345 million in annual revenue.

Scenario 2 performs substantially better in terms of travel speeds, vehicle trips, person trips, time savings, and gross revenue but will incur higher costs. The more moderate reduction in person trips to the charging area in Scenario 2 may be a more desirable result for downtown businesses concerned with the economic impacts of a congestion pricing charge.

Scenario 3 performs similarly to Scenario 1 in terms of revenue but is more in line with Scenario 2 in terms of travel outcomes. By providing the option of a time-based charge compared to a flat fee, it allows some drivers to save on charges, mainly those making shorter trips within the cordon.

Comparing between the Small and Large Downtown Study Areas, the latter eliminates more vehicle trips and produces more travel time savings. Scenarios in the Large Downtown Study Area generate substantially more revenue, since many more trips enter into this larger zone. Speeds improve, though by a lower percentage due to higher average speeds in this zone under baseline, recent conditions.

Scenario 4 (Figure 36) only charges a fraction of the trips entering downtown DC, those coming across the already-tolled facilities on I-66, and the I-395 HOT lanes. Therefore, it is estimated to shift a much smaller number of vehicle trips out of the peak period, compared to the full cordon scenarios. Nonetheless, Scenario 4 increases average speeds by 3% within the charging area (the whole of DC) and a produces substantial travel time savings, along with an annual revenue of $122 million.

Figure 36 Model Results from Congestion Pricing Scenarios 4 and 5

Scenario	Change in speeds within priced area (weekdays 24 hour)	Annual Gross Revenue	Change in volume of vehicle trips into priced area	Change in # of people entering priced area (% change for average weekday)	Daily traveler time savings (person-hours)
(4) Bridge Tolling	3%	$122 M	-2% -11,827 weekday; -6,100 weekend	-0.4% -6,700	22,000 daily 7 per year
(5) Pass-through Traffic Tolling	4%	$171 M	-3% -16,301 weekday; -8,773 weekend	-0.6% -8,900	30,000 daily 10 per year

Scenario 5 (Figure 36) attempts to estimate how many trips pass through DC – those that enter and exit without stopping to generate any useful activity, whether economic, educational, recreational, or commercial. The BTA-based results indicate that a significant number of trips could be diverted, with the remaining through-trips charged

incurring a revenue of $171 million. However, these results should be treated as a very rough starting point. The goal in charging pass-through trips is primarily route diversion (to streets and highways outside DC), not shifting travel mode or time-of-day. The BTA is not designed to predict route diversion. In addition, charging through-trips has not been implemented (or even studied in detail) in other settings. Communicating this unique approach to road pricing would be a challenge. While it is technologically feasible – noting time arriving and departing and charging if that was *below* some threshold – assessing the sheer number of monitoring points or appropriate OBU technology is not merited unless policymakers indicate support for this scenario.

Travel Mode Shifts

Travel mode shift is a key impact of congestion charging. Raising the cost of driving can shift trips from solo drives to shared rides (whether in private or for-hire vehicles), to transit, or to active modes including walking and biking. Many of the differences across Scenarios can be explained through the resulting mode shifts they cause.

Mode shifts for Scenarios 1, 2, and 3 are listed in Figure 37 and described below. Cells in the table highlighted in yellow indicate the largest beneficial mode shift among analyzed scenarios, while squares highlighted in orange indicate the largest undesired mode shift.

Figure 37 Mode Shifts for Scenarios 1-3 (Small Downtown Study Area)

Mode	Automobile		Other Vehicles		Transit			Active Modes
Scenario, Small Downtown Study Area	Work & commercial	Non-work	FHV	Truck	Metrorail	Metrobus & Circulator	Commuter Bus & Rail	Bicycle
Study Area Mode Split, Baseline (2017-2019) 1,088,400 trips	22.5%	34.5%	6.5%	1.8%	25.2%	4.9%	2.2%	2.4%
(1.S) Cordon (Inbound) 1,081,300 trips	22.4% -3,400	32.9% -19,200	7.0% +4,900	1.8% +100	25.9% +5,900	5.2% +3,100	2.2% -	2.6% +1,400
(2.S) Cordon (Inbound/ Outbound) 1,085,600 trips	21.9% -6,900	32.9% -17,300	7.2% +6,800	1.8% +200	26.1% +8,600	5.2% +3,600	2.2% -	2.6% +2,200
(3.S) Area Pricing (per min w/ Cordon opt) 1,086,700 trips	22.4% -1,600	32.9% -17,600	7.1% +6,000	1.8% +200	25.8% +6,200	5.2% +3,500	2.2% -	2.6% +1,500

As identified earlier, Scenario 2 reduces vehicle trips most significantly without incurring a significant reduction in overall travel because it drives mode shift from automobiles to transit, FHVs, and active transportation. It also drives more people to share rides (higher vehicle occupancy). FHV use increases in all congestion pricing scenarios, identifying a potential need for additional policy attention.

Mode shifts for Scenarios 1.L, 2.L, and 3.L are listed in Figure 38 and described below.

Figure 38 **Mode Shifts for Scenarios 1-3 (Large Downtown Study Area)**

Mode	Automobile		Other Vehicles		Transit			Active Modes
Scenario, Large Downtown Study Area	Work & commercial	Non-work	FHV	Truck	Metrorail	Metrobus & Circulator	Commuter Bus & Rail	Bicycle
Study Area Mode Split, Baseline (2017-2019) 1,420,100 trips	33.4%	27.2%	4.8%	1.9%	23.2%	5.1%	2.0%	2.4%
(1.L) Cordon (Inbound) 1,411,100 trips	33.7% +700	25.4% -27,200	5.1% +3,900	1.9% -100	24.0% +9,000	5.3% +2,600	2.0% -	2.6% +2,100
(2.L) Cordon (Inbound/ Outbound) 1,413,000 trips	33.6% -300	25.0% -31,900	5.2% +5,600	1.9% -	24.2% +13,200	5.3% +3,100	2.0% -	2.7% +3,200
(3.L) Area Pricing (per min w/ Cordon opt) 1,416,900 trips	33.9% +5,200	25.3% -27,900	5.1% +4,700	1.9% -100	23.9% +9,600	5.3% +3,100	2.0% -	2.6% +2,200

Mode shifts for the Large Downtown Study Area differ from the Small Downtown Study Area for Scenarios 1-3 in one particular respect: the share of work and commercial automobile trips increases in all scenarios, as compared to the baseline. The share of non-work-related automobile trips, however, decrease significantly across all scenarios in the Large Downtown Study Area, which is why the scenarios still reflect an overall decrease in vehicle trips.

Vehicle speeds are not projected to increase in the Large Downtown Study Area by as high a ratio as for the Small Downtown Study Area. The improvement in speeds is nevertheless enough to lead to a significant “rebound effect” whereby the reduction in non-work vehicle trips frees of road space for some workers to shift their commutes to driving. At the same time, more than twice as many trips shift to transit than shifting to driving.

Scenario 2.L out-performs other scenarios in terms of increasing Metrorail trips. Scenario 2.L also produces the highest shift to bicycle use compared to Scenarios 1.L

and 3.L. FHV trips increase for all scenarios, however Scenario 2.L (like 2.S) has the highest increase in FHV trips. Scenarios 1.L, 2.L, and 3.L show equal increases in Metrobus and Circulator trips, and no changes across truck, commuter bus, or commuter rail trips.

Scenario 4 charges only a portion (17%) of the total vehicle trips entering DC, and as a result, this scenario has a lower impact on mode shift across all trips within DC. In Scenario 4, mode shares (shown in Figure 39) increase for FHVs, Metrorail and Metrobus, and bicycle, while work, commercial, and non-work automobile trips decrease. Scenario 4 results in about the same decrease in work and commercial automobile trips as Scenario 1.S but has much less of an impact on non-work automobile trips.

Figure 39 Mode Shifts for Scenario 4

Mode	Automobile		Other Vehicles		Transit			Active Modes
Scenario	Work & commercial	Non-work	FHV	Truck	Metrorail	Metrobus & Circulator	Commuter Bus & Rail	Bicycle
DC-wide** Mode Split, Baseline (2017-2019) 1,590,800 trips	28.5%	20.9%	2.6%	1.7%	24.8%	17.5%	1.5%	2.4%
(4) Bridge Tolling 1,584,100 trips	28.5% -3,000	20.5% -7,600	2.7% +300	1.7% -200	25.1% +2,500	17.6% +600	1.5% -	2.5% +500

Societal Net Benefits

The BTA provides an estimate of the overall societal net benefit of each congestion charging scenario. This estimate incorporates direct costs (measured in dollars and dollar-converted time) as well as indirect costs (also monetized) to assess whether the environmental, social, and economic benefits of a congestion program outweigh capital expenses, costs to vehicle users, and any other potential costs due to a congestion pricing program.

Scenario 1.S incurs an estimated total of $500 million in societal benefits and over $400 million in societal costs. With $345 million in predicted gross revenue, total societal net benefit is $417 million. Scenarios 2-5 show roughly proportional societal net benefits, where the largest ‘gains’ are from time savings and revenues and the highest ‘costs’ are congestion charges (user fees). These costs and benefits can be included along with other measures of effectiveness when considering both the selection of a pricing approach and the presentation of it to various constituencies.

The various benefits and their monetized ‘gains’ and ‘costs’ for the community are listed below in Figure 40 and shown visually in Figure 41.

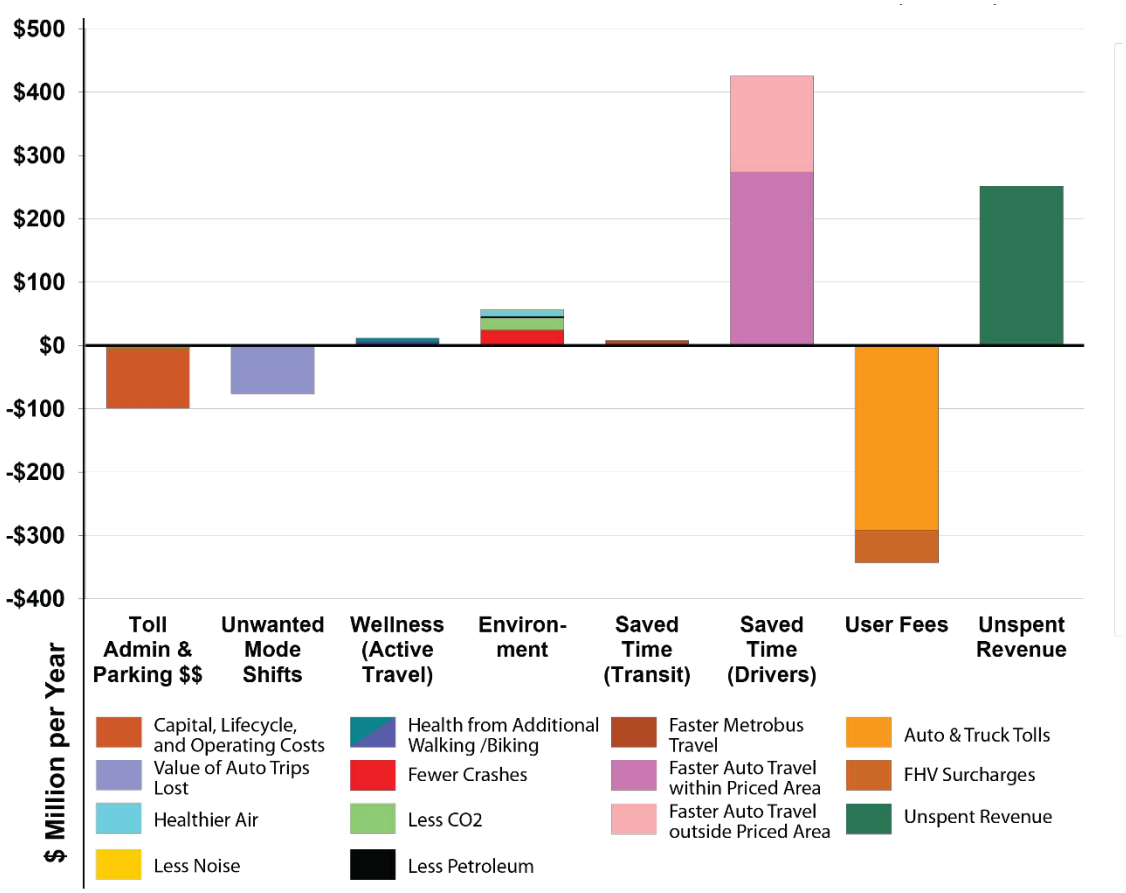
Figure 40 Societal Net Benefits for Scenario 1.S

Scenario 1.s: Economic, Social, and Environmental Costs and Benefits	Annual $, millions*
Benefits	
Saved Time: Value of Transit Riders' saved time due to reduced congestion and/or transit service improvements	8
Saved Time: of Motor vehicle users' saved time that was previously lost due to congestion (in priced area)	274
Saved Time: Value of Motor vehicle users' saved time that was previously lost due to congestion (outside priced area)	152
Environment: Reduction in crash damage costs	25
Environment: Reduction in climate damage from reduced CO2 emissions	19
Environment: Reduction in ecological and national-security costs from reduced petroleum use	3
Environment: Reduction in air pollution health/environmental damages	9
Environment: Reduction in noise	1
Wellness: Health benefits of increased cycling	6
Wellness: Health benefits of increased walking	6
Revenue	
Unspent revenue	252
Fees/Costs	
User Fees: Auto & truck tolls	-291
User Fees: For hire vehicle surcharges	-51
Parking: Lost parking revenues	-6
Unwanted Mode Shifts: Value of automobile trips lost	-76
Toll Administration: Capital Expense**(Annual Cost over a 5 year-period), Annual Lifecycle Cost, Annual Operating Costs	-93
Total Societal Net Benefit	$238

*Rounded to the nearest million

**Five-year amortized capital expense

Figure 41 Societal Net Benefits and Costs



Scenario 6

A review of available literature suggests that parking price has an elasticity of demand of around 0.3, meaning that each 1% increase in price results in a 0.3% decrease in demand[34]. This elasticity factor largely applies to work travel trips, and only correlates price and demand, not price and trip-making.

The parking price increase from $2.30 to $3.55 is a 54% increase, which at an elasticity of 0.3, implies a reduction in the demand for on-street parking of 16%. The level of current utilization within the Downtown Study Areas of on-street parking lasting the whole workday is unknown. According to Seattle data collected[35] during the BTA development, between 5-20% of work trips pay to park in on-street parking spaces. This proportion fluctuates over the course of the day, but averages 15% of work trips utilizing on-street parking. Based on these assumptions, the proposed parking pricing increase could decrease demand for on-street parking spaces by 5,956 car spaces in the Small Downtown Study Area and 11,540 spaces in the Large Downtown study area. See Figure 42 for details. Compared to the other congestion pricing scenarios, which estimate reduced vehicle trips on weekdays ranging between 29,000 and 64,000, Scenario 6 would likely result much lower reductions in vehicle trips.

Figure 42 Scenario 6: Estimated Decrease in On-Street Parking Demand

Scenario, Study Area	Baseline: Auto work & commercial trips	Percent of work trips using on-street parking	Parking Price Increase to Parking Demand Change	Parking Price Increase ($2.30 to $3.55)	Parking Demand Change	Estimated Number of Work Trips Changed/ Converted
Small Downtown Study Area						
(6.S) On-Street Parking Pricing	245,100	15% 36,765	-0.30	54%	-16.2%	-5,956
Large Downtown Study Area						
(6.L) On-Street Parking Pricing	474,900	15% 71,235	-0.30	54%	-16.2%	-11,540

Limitations of Scenario Findings & Considerations for Future Studies

A decrease in the demand for on-street parking cannot be interpreted as directly leading to a decrease in the number of vehicle trips or person trips. Some workers will still travel into the pricing area and instead change parking behavior by parking in privately controlled off-street facilities where price increases did not occur. Moreover, the parking pricing scenario tested here incorporated a flat fixed rate increase in on-street parking prices, which imposed a $3.55 hourly parking rate throughout the day. Flat and fixed rate price increases will decrease demand and, at times of the day, could result in a supply abundance when less than the optimum number of parking spaces are utilized (85% is target[36]). The parkDC demand-based parking pricing program is a more successful approach to temporally managing parking demand and could result in minor reductions in congestion and secondary impacts such as reductions in emissions and traffic collisions. If on-street parking pricing were to be studied further for implementation, then a demand-based parking pricing program should be prioritized, as a program such as this, paired with a traditional congestion pricing scheme, could be a highly effective way to reduce vehicle trips.

REFINED SCENARIOS AND RESULTS

The main Scenarios were initially defined with similar parameters to understand the type and scale of differences due to just the alternative pricing approaches. However, a subsequent sensitivity analysis varying the charging price and charging time period presents more detail around scenarios' impacts, effectiveness, and implementation feasibility. Further refinements to the scenarios can also help to measure the potential impacts of a low-income driver exemption or targeted revenue reinvestments for transit.

Adjusting the congestion pricing scenario parameters allows for an examination of the relative changes to revenue, trip numbers, and time savings. To aid interpretation, comparisons are made using Scenario 1.S as a base case, as the direction and rough magnitude of changes in Scenario 1.S should be similar to the other cordon-based

scenarios and study areas. Variations in the toll, charging time periods, and days of charging are also examined for Scenario 4.

Sensitivity to Varying Price and Charging Times

Sensitivity to adjustments to price (reduction by 50%), days of the week (eliminating weekends), and times of day (adding pm peak) are described in Figure 43.

Figure 43 Refinements to Scenario 1.S to Charged Price, Charging Times, and Charging Days

Scenario, Study Area, Charge Details	Change in speeds within priced area (weekdays 24hour)	Annual Gross Revenue	Change in volume of vehicle trips into priced area	Change in # of people entering priced area (% change for average weekday)	Daily traveler time savings (person-hours)
Scenario 1.S: Cordon (Inbound) Scenario, Small Downtown Study Area					
Weekday am peak charge					
(1.S) $10 weekday am peak $5 weekend all day	19%	$345 M	-7%	-0.7%	40,800
(1.Sa) $10 weekday am peak no weekend charge	19%	$260 M	-6%	-0.7%	40,800
Weekday am/pm peak charge					
(1.Sb) $10 weekday am/pm $5 weekend all day	23%	$440 M	-10%	-0.3%	50,400
(1.Sc) $10 weekday am/pm no weekend charge	23%	$355 M	-9%	-0.3%	50,400
(1.Sd) $5 weekday am/pm $5 weekend all day	14%	$290 M	-6%	-0.2%	33,800
(1.Se) $5 weekday am/pm no weekend charge	14%	$205 M	-5%	-0.2%	33,800

Note: Cells highlighted in yellow indicate the highest beneficial change among analyzed scenarios.

Removal of the weekend congestion charge (Scenario 1.Sa) results in lower revenues, but does not change the number of vehicle or person trips significantly. When the charging time period changes from am peak only (Scenarios 1.S and 1.Sa) to both am and pm peak hours (Scenarios 1.Sb and 1.Sc), vehicle trip reductions increase while

person trip reductions decrease. When charging price decreases by half from $10 to $5 (Scenarios 1.Sb vs. 1.Sd and 1.Sc vs. 1.Se), less revenue is generated, and other beneficial impacts to vehicle trip reductions and vehicle speed increases are not as significant. However, the scenarios that charge only $5 on weekdays remain viable from an implementation perspective and could be a means to introduce congestion charging in the region.

Varying the charging time and price for Scenario 4 resulted in similar changes as shown in Figure 44. Scenario 4a (removing the weekend charge) produced less revenue, and slightly reduced vehicle trips. Scenario 4b (charging in am and pm peaks) incurred the highest revenue, vehicle speed gains, and traveler time savings. This scenario reduces twice as many person trips as Scenario 4c, which proposes a $5 am and pm peak charge without the weekend charge.

Figure 44 Refinements to Scenario 4 to Charging Time and Price

Scenario, Study Area, Charge Details	Change in speeds within priced area (weekdays 24hour)	Annual Gross Revenue	Change in volume of vehicle trips into priced area	Change in # of people entering priced area (% change for average weekday)	Daily traveler time savings (person-hours)
Scenario 4: Bridge Tolling Scenario					
Weekday am peak charge					
(5) $10 weekday am peak $5 weekend all day	3%	$122 M	-2%	-0.4%	22,000
(4a) $10 weekday am peak; no weekend charge	3%	$87 M	-1%	-0.4%	21,900
Weekday am/pm peak charge					
(4b) $10 weekday am/pm; no weekend charge	4%	$132 M	-2%	-0.6%	29,100
(4c) $5 weekday am/pm; no weekend charge	2%	$72 M	-1%	-0.3%	15,800

Note: Cells highlighted in yellow indicate the highest beneficial change among analyzed scenarios.

Providing More Benefits to Low-Income Travelers

Targeted exemptions from congestion charges and investment of charging revenue into transit service and/or fare reduction can provide additional benefit to low-income travelers. These refinements to congestion charging scenarios have the potential to increase the positive impacts (transit investments) and decrease the negative impacts

(exemptions) of congestion charging. Exemptions to low-income travelers and investments in transit were analyzed separately and in combination with each other, and the outputs are shown in Figure 45.

Scenario 1.Sf assumes an exemption to the congestion charge for all low-income drivers, estimated to be 2% of the total number of drivers[d]. As described in Section 2, the number of low-income people currently driving to commute into the Small and Large Downtown Study Areas for work is quite low: for the Small Downtown Study Area, about 1.4% of all workers commuting to the area by vehicle earn less than $37,500 annually, just over 6,000 employees.

Transit investments can expand or improve existing transit systems or reduce fares for selected transit riders. Such investments incentivize increased transit ridership by improving the rider experience, decreasing commute times, or enhancing access. Transit investments incorporated into the refined Scenarios 1.Sg and 1.Sh include: $90 million annual spending on transit upgrades and expansions and $100 million and $50 million annual spending on Metrobus and Metrorail operations, respectively.[e]

Figure 45 Refinements to Scenario 1.S - Exemptions for Low-Income DC Residents, and Reinvestment of Revenue in Transit

Scenario, Study Area, Refinements	Change in speeds within priced area (weekdays 24hour)	Gross Annual Revenue; Net Income	Change in volume of vehicle trips into priced area	Change in # of people entering priced area (% change for average weekday)	Daily traveler time savings (person-hours)
Scenario 1.S: Cordon (Inbound) Scenario, Small Downtown Study Area					
(1.S) No exemptions or investments	19%	$345 M; $252 M	-7% -29,422 weekday; -12,793 weekend	-0.7% -7,100	40,800
(1.Sf) Low-income exemptions*	18%	$340 M; $249 M	-7% -29,026 weekday; -12,644 weekend	-0.6% -7,100	40,400
(1.Sg) Transit investments**	19%	$340 M; $8 M	-8% -29,975 weekday; -13,022 weekend	-0.4% -4,600	41,200
(1.Sh) Low-income exemptions* with Transit investments**	19%	$340 M; $9 M	-8% -29,580 weekday; 12,874 weekend	-0.4% -4,400	40,800

[d] In the BTA model, this is accomplished by adjusting the share of automobiles that are charged the congestion fee.

[e] The estimated net revenues for Scenarios 1-3 are greater than $250 million, which guided the selected amount of transit investments for the analysis in Figure 45.

*Low-income exemptions assume that 2% of all autos entering the study area are exempt from the cordon charge. Two percent is slightly more than the estimated 1.6% of all workers that are low-income earners that use a vehicle to commute to work.

**Transit investments incorporated into the model include: $100 million annual spending on transit upgrades and expansions (BTA Policy Lever 26), $100 million and $50 million annual spending on Metrorail and Metrobus operations, respectively (BTA Policy Lever 27).

Compared to Scenario 1.S, providing exemptions from the congestion charge to low-income drivers reduces revenue by $5 million, while the number of vehicle trips remains roughly the same. This demonstrates that any pricing scenario should be able to exempt low-income travelers from paying a congestion charge without affecting the underlying feasibility of a scenario. Congestion pricing with a low-income exemption could help to reduce transportation burdens on low-income persons, while also easing traffic on the street for both drivers and bus riders. In other words, low-income travelers would experience better performance whether driving (without congestion charges) or taking transit (with improved performance).

Compared to Scenario 1.S, reinvesting congestion pricing revenue in transit service results in a $5 million decrease in gross revenue as shown by Scenario 1.Sg, due to a decrease in vehicle trips as more people shift to transit. Scenario 1.Sg results also show a greater reduction in vehicle trips, a smaller reduction in person trips, and higher daily traveler time savings – all attributable to higher transit ridership caused by mode shift in response to transit improvements.

When low-income exemptions are paired with transit investments (Scenario 1.Sh), all measures improve compared to Scenario 1.S, with the exception of the $5 million revenue decrease. If investments are directed towards enhancing access to neighborhoods with higher low-income populations or longer transit commute times, the most transportation-disadvantaged neighborhoods could see improved access and efficiency of service.

EVALUATING SCENARIOS AGAINST EQUITY METRICS

Section 1 described a set of equity-focused metrics against which any pricing scenario must be evaluated. Scenarios must avoid any negative impacts to people, neighborhoods, and communities already facing transportation-related disadvantages and should put in place mechanisms that amend inequities in the city's transportation system.

Given the expected impacts by travel mode described in Section 1, the Scenario analysis results show that with appropriate low-income exemptions and transit investments, congestion pricing programs can benefit all residents, employees, and visitors of DC. Figure 46 outlines potential impacts that each congestion pricing scenario may have in relation to the study's identified metrics.

Figure 46 Congestion Pricing Scenario Impacts to Equity Metrics

Scenario (see below for brief descriptions)	Access & Affordability	Efficiency	Health	Safety
Cordon (Inbound), Small & Large Study Area (1.S, 1.L) Cordon (Inbound/Outbound), Small & Large Study Areas (2.S, 2.L) Area Pricing, Small & Large Study Areas (3.S, 3.L)	Access by vehicle would be limited to drivers able or willing to pay the fee during charging hours. Access could be increased for other modes through investment in transit and/or infrastructure for active transportation.	Efficiency/ speed on roads internal to the cordon would be improved for those willing to pay the fee. Some speed efficiencies could be gained on roads outside of the cordon, however some diverted trips could further congest these roads.	Reduced vehicle trips both in the charging area and outside of the charging area would improve air quality by reducing total driving, idling from congestion.	Increased vehicles speeds would need mitigation to minimize the risk of increased traffic crashes. Congestion pricing revenue could help fund safety improvements to bicycle and pedestrian infrastructure.
Bridge Tolling (4)	Access to DC from Virginia using the tolled facilities would be limited to drivers willing to pay. Drivers opting out of the charge would be required to divert their trip; while access to any specific part of DC would not be limited, those unwilling to pay would need to change their route. Access could be increased for other modes through investment in transit and/or infrastructure for active transportation.	Efficiency across the tolled facilities would be improved for drivers willing to pay the fee. Efficiency/ speed could be impacted for other non-tolled facilities; these facilities may experience greater congestion.	Reduced vehicle trips across state lines could improve air quality in DC and regionally.	Congestion pricing revenue could help fund bicycle network expansion projects throughout the area and especially along tolled roadways to provide safe and suitable alternatives to driving.

Scenario (see below for brief descriptions)	Access & Affordability	Efficiency	Health	Safety
Pass-through Traffic Tolling (5)	Access would be prioritized for residents, employees, and visitors to DC, since pass-through traffic would be the only charged vehicles.	Efficiency and driving speeds for internal DC trips would improve, as through-traffic vehicles are diverted and congestion on arterials is reduced.	Air quality would improve in areas near DC's high-trafficked arterials as vehicle trip numbers are reduced.	Road safety would improve with less through-traffic on DC roads, however mitigation may be required to ensure that greater efficiency (and potentially higher speeds) do not result in more traffic crashes.
On-street Parking Pricing, Small & Large Study Areas (6.S, 6.L)	Access would be limited to drivers able or willing to pay higher rates during charging hours.	Congestion would be decreased as fewer vehicles would circle blocks for parking spaces. Parking pricing schemes that effectively manage curbside activities could reduce double parking, reducing conflicts and delays.	A localized decrease in congestion could improve air quality within the downtown area where parking rates increase.	Revenue could help fund safety improvements to bicycle and pedestrian infrastructure. Parking pricing schemes that effectively manage curbside activities could reduce double parking, reducing conflicts.

SECTION 5: CONCLUSION AND NEXT STEPS

PLANNING DURING UNCERTAIN TIMES

In late 2019, local and regional traffic in and around DC was endemic along with the strong regional economy. As the global COVID pandemic began in early 2020, traffic volumes declined and traffic patterns changed. The region's sharp increase in telecommuting has softened the office market in downtown DC and drastically reduced demand for regional transit. As the pandemic continues, predictions vary on how and when our region will rebound from these changes. But even with these unknowns, it is important to plan and set the stage for a congestion pricing program now so that once congestion returns and demand for our roadways, transit systems, and commercial real estate rebounds, a program can more swiftly be put in place and congestion does not create an obstacle to economic recovery and growth for business districts. Public conversations about the benefits of congestion pricing can help guide decision-makers on an appropriate path forward. Further study and development of a congestion pricing program could include analysis of impacts on real estate development and demand which could help inform and refine the proposed charging area and various charging policies.

FURTHER MODEL ANALYSIS

This study's products include a version of the BTA model calibrated to DC local and regional conditions. The model includes the three defined study areas and the many pricing scenarios analyzed in this study. As DCST, DDOT, and other stakeholders continue to develop and refine a congestion pricing program and its various components, the model can be used to test pricing parameters and evaluate impacts on revenue, trip volumes, and overall benefits to the community. DCST and DDOT will consider making the model available to other non-profit or academic entities that could support analysis into the various permutations of cordon-based and related congestion pricing programs.

IDENTIFICATION OF REVENUE ALLOCATION

When London executed their congestion pricing scheme, the city increased its bus service by 27%. The added transit provided Londoners ample transportation opportunities comparable to private vehicle travel. In addition to added buses, roadway capacity can be re-envisioned; for example, a four-lane road could be converted to a two-lane road with dedicated bus lanes – or protected car free lanes for bicycles and buses. For a congestion pricing program to succeed in DC, transit service would need to be improved – and prioritized – in tandem with or in advance of beginning congestion charges. DDOT should utilize moveDC's finalized Transit Priority Network, Bicycle Priority Network, and Pedestrian Improvement plans to develop a list of projects that could support (and possibly be funded by) a congestion pricing program. Projects located within transportation-burdened areas (as identified in Section 2) or areas of high transportation need (as identified through moveDC's analysis) should be prioritized for

inclusion in the project list. As discussed above, regional projects (not necessarily located within DC) could also be considered for funding.

AGENCY COLLABORATION AND JURISDICTIONAL COORDINATION

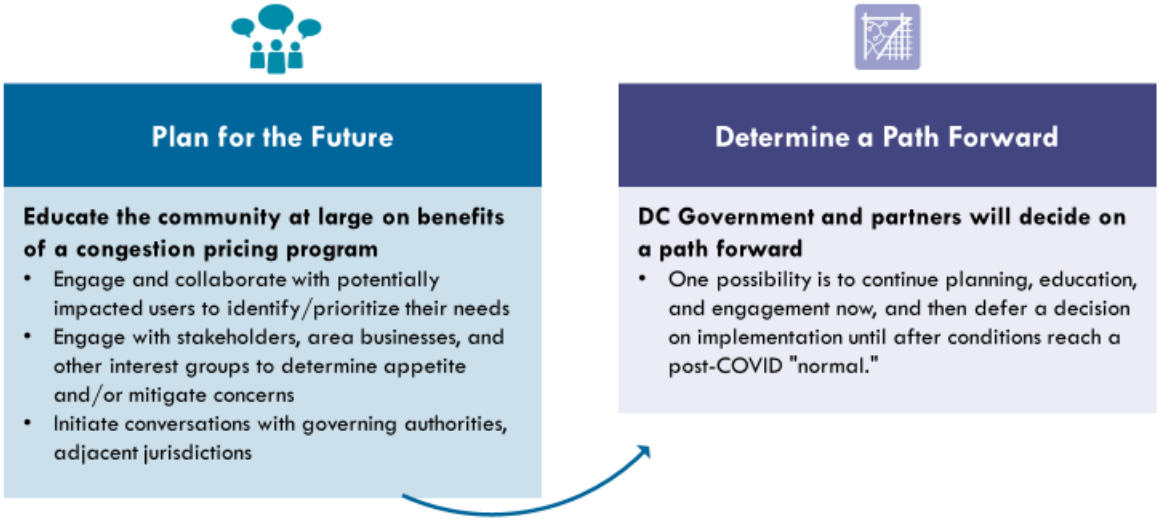
Collaboration between advisory and regulatory agencies as described in Section 3 should begin as soon as possible to develop a clear pathway through the required review and approval processes. Informational meetings with these groups can help to introduce the goals of congestion pricing while establishing or affirming relationships with various agency partners.

With DC's Home Rule government, Congress holds approval authority over DC's budget and all legislation passed by the DC Council. Therefore, like other major policies, the Mayor's Office and DC Council should liaise with DC, Virginia, and Maryland Congress representatives and coordinate meetings with other representatives to discuss the need for and benefits of congestion pricing.

COMMUNITY AND STAKEHOLDER ENGAGEMENT

A well-designed community engagement and outreach effort is an essential aspect of any policy change, especially one that assesses a new fee to residents. Efforts to engage DC residents, employees, and employers in dialogue regarding their needs and concerns related to transportation should begin immediately. The intent of these outreach efforts should be to better understand the needs of communities and to demonstrate how a congestion pricing policy can be a tool to meet them. Across the world, congestion pricing programs have experienced their lowest levels of support immediately before implementation. But, once the effects and benefits are witnessed, public support has quickly increased. As residents hear about how congestion pricing can improve traffic flows, make transportation more efficient, balance inequitable transportation in the region, and generate revenue for further transit investment, the program stands to gain community support that should endure as it moves from planning to approval to implementation (Figure 47).

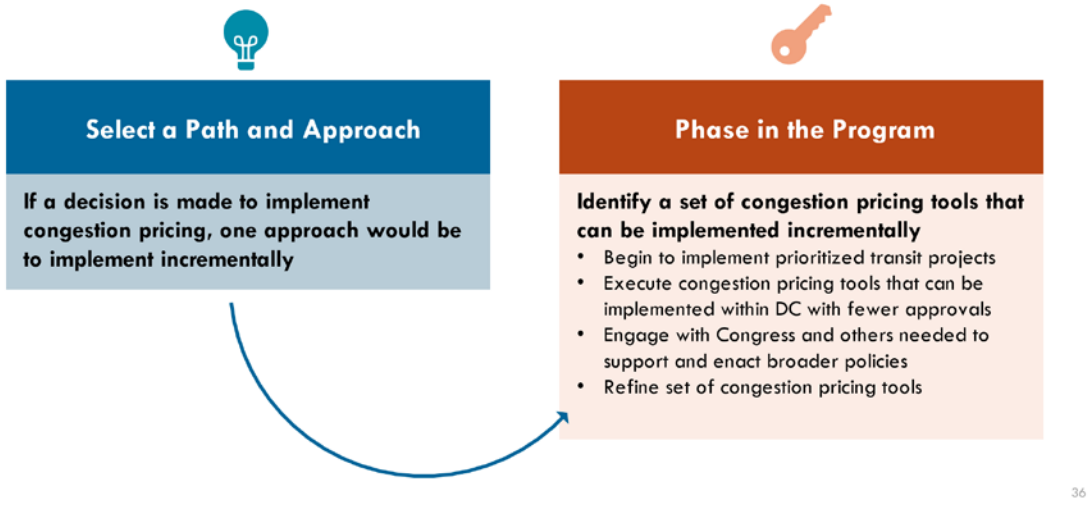
Figure 47 Start Public Conversation About Program Goals

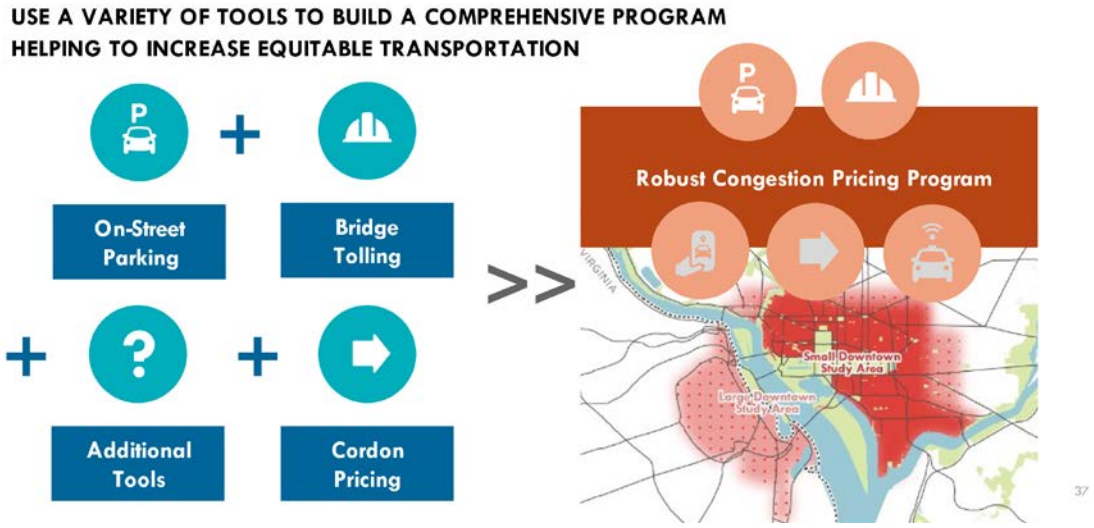

Plan for the Future
Educate the community at large on benefits of a congestion pricing program
• Engage and collaborate with potentially impacted users to identify/prioritize their needs
• Engage with stakeholders, area businesses, and other interest groups to determine appetite and/or mitigate concerns
• Initiate conversations with governing authorities, adjacent jurisdictions
Determine a Path Forward
DC Government and partners will decide on a path forward
• One possibility is to continue planning, education, and engagement now, and then defer a decision on implementation until after conditions reach a post-COVID "normal."
35

ONE POTENTIAL PATH FORWARD: INCREMENTAL IMPLEMENTATION

This study's cited goals for congestion mitigation and sustainable mode shifts with a lens for equitable access would be well-served by a robust congestion pricing program as described in previous sections. While implementing a comprehensive program will take considerable further study, negotiation, and planning, smaller discrete policies could be enacted incrementally to build toward an ultimate multi-pronged strategy (Figure 48).

Figure 48 One Potential Path Forward


Select a Path and Approach
If a decision is made to implement congestion pricing, one approach would be to implement incrementally
Phase in the Program
Identify a set of congestion pricing tools that can be implemented incrementally
• Begin to implement prioritized transit projects
• Execute congestion pricing tools that can be implemented within DC with fewer approvals
• Engage with Congress and others needed to support and enact broader policies
• Refine set of congestion pricing tools
36



Some of the scenarios analyzed in this study may serve best as components to a larger congestion pricing program. For instance, Scenario 4 (Bridge Tolling) and Scenario 6 (On-Street Parking Pricing) could serve as initial phases leading ultimately to a cordon-based pricing scenario similar to Scenarios 1, 2, or 3. Scenarios 4 and 6 can be enacted independently of each other and perhaps would not require extensive installation of pricing equipment or complex agency approvals. As these programs roll out, they could be identified as part of DC's holistic and phased approach to congestion management. A communications and branding campaign could help establish and socialize the goals and strategies among DC residents, employees, and visitors. Starting with the concepts of congestion pricing and its direct connection to improving equity could help announce the beginning of an incremental, long term program to price transportation in DC equitably and efficiently.

Initial Steps for a Robust Pricing Policy:

- DDOT could work to expand their demand-based on-street parking program to a larger area, perhaps up to the Small Downtown Study Area boundaries.
- DC Council could call for DDOT to begin work with FHWA and other governing authorities to implement bridge crossing charges for I-66 and the I-395 Express Lanes, as these bridges form part of the boundaries of the Small Downtown Study Area.
- DC could develop an innovative congestion pricing pilot that tests emerging technology and its ability to provide cost-effective, secure, flexible pricing.
- DC Council could empower the Mayor to begin discussions with the surrounding jurisdictions on regional transportation funding that could include congestion pricing, ticket reciprocity, and the distribution of funds among regional priorities including Metro and other sustainable transportation needs.

Appendix A Review of Parallel Plans

Within the region a number of recent plans, studies, and reports challenge the status quo of the transportation system. These documents provide guidance on elements that are critical for a sustainable transportation system to survive and thrive in DC and across the region. Many of the plans are already being implemented and will support changes in DC from an equity, climate, transportation, and health perspective. The plans and studies reviewed helped to frame this project's vision and goals and are summarized below.

moveDC (2014) & moveDC Update (2021)

MoveDC, DC's long-range transportation plan, is being updated and will be completed in 2021. The current moveDC plan, completed in 2014, laid out a progressive strategy for a sustainable transportation system, which included a congestion charging zone for the downtown area and tolled express lanes at major entry points to DC.

The moveDC update aims to apply an equity framework to the development of the plan and focuses on underserved communities. The six goals of the update include:

- **Safety:** DDOT will design and manage a transportation network that offers safe and secure travel choices for all users, in accordance with Mayor Bowser's Vision Zero initiatives.
- **Mobility:** DDOT will increase system reliability, improve accessibility, and manage congestion through coordination, communications and mobility options, providing safe and affordable travel choices for all users and trips.
- **Management and Operations:** DDOT will ensure the state of good repair for existing assets by investing in maintenance and operations to address the greatest mobility needs.
- **Project Delivery:** DDOT will complete projects on-time and on-budget while engaging and communicating with the community.
- **Sustainability:** DDOT will manage and promote a transportation network that supports economic vitality and opportunity, reduces emissions and strengthens resilience in the face of climate change, especially in historically underserved neighborhoods that may experience greater impacts.
- **Enjoyable Spaces:** Public spaces and transportation systems managed by DDOT will be accessible, safe, and welcoming to residents, visitors and commuters.

DDOT Bus Priority Network Plan (2019)

More DC residents ride the bus each day than Metrorail. However, over the last decade, average bus speeds have declined. To enhance the bus service District wide, DDOT is working to improve bus travel speeds and reliability through a series of bus priority projects and program areas.

A Bus Priority Program will assist DDOT in identifying bus priority corridors and enable the development of a toolbox of improvements, like bus lanes, to help improve bus speeds and reliability.

Comprehensive Plan (2020)

The vision for a more equitable DC is primarily expressed through its Comprehensive Plan. The Comprehensive Plan is currently undergoing Council review, but the most recent draft (April 2020) has significantly strengthened how it addresses dimensions of equity.

The Comprehensive Plan includes several major themes: COVID-19 and recovery, equity and racial justice, housing, resilience, and public resources. The plan specifically states that "[s]upporting growth through an equity lens provides opportunities for understanding that vulnerable populations and neighborhoods need additional attention to share in the prosperity of DC." Plan DC also includes a specific Transportation Element that describes the role of the transportation system in promoting DC's vision and values.

"400.3 A safe well-balanced and multi-modal transportation system is integral to the city's efforts to sustain and enhance the quality of life and key to its future economic growth and its role as the nation's capital. Achieving such a system requires integrating land use and transportation, and implementing a range of improvements that enhance safety, connectivity, livability, equity, health, sustainability, resiliency and vitality."

This language will inform the forthcoming update to the DC transportation plan, moveDC and provides important guidance for this study's project team to assess the equity in the performance of the transportation system.

Sustainable DC 2.0 (2019)

Since the original Sustainable DC plan was released in early 2013, DC has achieved great progress in becoming more sustainable. Since its publication in 2013, Sustainable DC has provided a framework for more detailed individual plans undertaken by DC. While Sustainable DC touches on many topics including equity, climate, transportation, and health, individual plans are more focused. Specific objectives related to transportation and equity include:

- Improve connectivity and accessibility through efficient, integrated, and affordable transit systems. | Target: 50% transit commutes by 2032.
- Safe & connected walk & bike infrastructure. | Target: 25% walk and bike commutes by 2032.
- Affordable & convenient choices. | Target: down to 25% drive commutes by 2032.
- Reduce GHG & air pollution. | Target: 60% reduction.

District Mobility (2017)

The District Mobility tool and study includes measures of congestion, reliability, and accessibility. It focuses on all modes of transportation and provides information by Ward

and neighborhood geography. Because it assesses information at fine-grained geographies, it offers valuable insight into inequities in system performance. Its eleven performance measures are:

- Commute mode split
- Commute time
- Travel time index
- Travel time reliability
- Bus speed
- Bus ridership
- Bus on-time performance
- Bus coverage area
- Bicycle level of traffic stress
- Bicycle coverage area
- Pedestrian friendliness

Vision Zero Action Plan (2015)

The Vision Zero Action Plan commits to four priorities with the goal that, by the year 2024, Washington, DC will achieve zero traffic fatalities and serious injuries on its streets, through more effective use of data, education, enforcement, and engineering. The plan also calls finer geographic level traffic safety data to enable better monitoring and prioritization of resources.

- **Create Safe Streets**, with 10 implementing strategies. Includes ensuring geographic and social equity of investments and improvements.
- **Protect Vulnerable Users**, with 21 strategies. Vulnerable users include the young and old, and all people walking or biking.
- **Prevent Dangerous Driving**, with 22 strategies
- **Be Transparent and Responsive**, with 14 strategies

Clean Energy DC (2018) & Progress Report (2020)

Clean Energy DC is DC's climate and energy plan. It explains how DC will use forward-looking energy policies to achieve its greenhouse gas (GHG) emissions targets of reducing emissions 50% below 2006 levels by 2032 and achieving carbon neutrality by 2050. Both goals are consistent with the global effort to fight climate change as identified in the 2016 Paris Agreement. Achieving a 50% reduction in GHG emissions by 2032 is essential to putting DC on the path to achieve carbon neutrality by 2050. It lists 57 emission reduction actions for the short- and long-term focusing on transportation, utilities, buildings, development, neighborhoods, communities, governance, and implementation in DC.

Climate Energy DC specifically sought to account for the disproportionate climate change impacts on frontline communities by considering social and economic indicators - including poverty, health indicators, and age - as part of its vulnerability analysis. The plan found that Wards 7 and 8 are most vulnerable to climate change given high levels

of unemployment, poverty, obesity, asthma, and the large number of elderly people. The plan also found that Ward 7 is home to the largest number of vulnerable community resources, including schools, medical services, and public housing that sit along the flood-prone Watts Branch tributary. The Climate Energy DC plan has already begun implementation of some actions, according to the plan's 2020 progress report.

Health Equity Report (2018)

The Health Equity Report provides a baseline assessment of health equity issues and opportunities in Washington DC. The report uses population health data on the leading causes of death and projected life expectancy at birth in conjunction with social and economic data and geographic information systems (GIS) to identify opportunities to improve health outcomes across the city.

Chapter 11 presents data on transportation metrics at the City, Ward, and neighborhood levels, primarily developed from Census data sources. It relates those data to health outcomes including life expectancy.

MWCOG Visualize 2045 Plan (2018)

Visualize 2045 is the federally required long-range transportation plan for the National Capital Region. It identifies all regionally significant transportation investments planned through 2045 and provides detailed analysis to help decision makers and the public "visualize" the region's future under current plans. The Plan outlines seven initiatives in Visualize 2045 that, if realized, have the potential to significantly improve the region's transportation system performance. These initiatives are:

1. Bring jobs and housing closer together
2. Expand bus rapid transit and transitways
3. Move more people on Metrorail
4. Increase telecommuting and other options for commuting
5. Expand the express highway network
6. Improve walk and bike access to transit
7. Complete the National Capital Trail

The plan also includes the identification of unfunded projects. As of 2015:

- WMATA had identified $8,707 million in short- and long-term projects in the Momentum Plan and $30,302 million in short- and long-term projects in the Connect Greater Washington Plan
- DDOT had identified from the MoveDC plan: $196.35 million for 149.5 miles of bicycle and pedestrian projects, $173 million for 21.4 miles total of Tier 2 transit projects, $101 million for 19.2 miles of Tier 3 transit projects and $171 million for 13 miles of Tier 4 transit projects.

WMATA Bus Transformation Project (2019)

Regions around the US and world have transformed their bus systems to achieve reductions in congestion, improvements in reliability, and to provide fast and frequent service. WMATA's Bus Transformation Project follows suit and identifies four key recommendations with the understanding that "rapid, effective surface transportation is critical to our region's prosperity". The Project sets out an ambitious future strategy and details 26 recommendations with proposed project schedules, case studies, and status updates. Regarding the plan's goal of creating a bus system that is affordable and equitable, WMATA has outlined the following three objectives:

- Ensure equitable transit service for those who most depend on it
- Provide riders with affordable end-to-end transportation
- Enhance mobility options for people with disabilities

Appendix B Balanced Transportation Analyzer

Model Vetting

Shortly after its initial form took shape, the BTA model began to be used by MoveNY, a coalition of transportation and environmental advocates that formed to study and advocate for more equitable and efficient pricing systems for New York's roadways and transit systems, including congestion pricing. As it was an untested transportation analysis tool, MoveNY engaged the modelling team of HNTB, an international engineering firm, to audit the model in 2013. In their vetting process, HNTB found the BTA to be, overall, "comprehensive, dynamic, transparent, and realistic." The audit also compared the model's projections to cities that already had a form of congestion pricing in place (London, Stockholm, and Singapore) and found its outputs to be "consistent" with real-world operations.[37] Based on this assurance from an expert modelling team, MoveNY continued to rely on and advance the BTA as the primary congestion pricing analysis tool in their advocacy to New York elected officials.

Governmental Applications

From the fall of 2017 into early 2019, the BTA model was the primary tool relied on by the "Fix NYC" task force convened by New York Governor Andrew Cuomo to identify ways in which congestion pricing could create a new, robust, and sustainable stream of funding for the Metropolitan Transportation Authority (MTA) while also reducing chronic traffic gridlock in and on the approaches to the Manhattan central business district (CBD).

Based in part on the model's assessment, the task force recommended a charge of $11.52 be instituted for passenger cars entering the proposed CBD congestion zone in Manhattan, south of 60th Street. The task force also recommended a toll surcharge for taxis and for-hire vehicles (e.g., Uber and Lyft), which at that time accounted for approximately half of vehicle-miles traveled within the proposed congestion zone.

A form of the plan that hewed closely to the Fix NYC recommendations was adopted by Governor Cuomo and the state legislature in early 2019, for implementation in 2021. However, implementation has been delayed by the Federal Highway Administration's refusal to specify the scope of the environmental review process required for federal approval.

While the BTA model was created specifically to analyze the transportation environment of New York City, its structure allows it to be adapted for other localities, and it has since been used to evaluate potential congestion pricing schemes for the City of Seattle, Washington. Since 2019, the Seattle Department of Transportation (SDOT) has deployed a Seattle-specific version of the BTA to evaluate the cost-benefit of congestion pricing for the city's downtown commercial and cultural core. This version incorporates a number of changes tailored to local conditions (for example, the pronounced difference in transit and taxi modes between Seattle and New York), in order to examine four different pricing schemes for two alternative congestion zones for their impacts on

equity, climate, traffic congestion, and implementation feasibility.[38] The results are an initial part of an ongoing effort by city leadership to engage the community in the future of Seattle's transportation system.

Data Inputs

Key input data to the BTA model includes baseline vehicle counts into and through the proposed congestion zone (broken down by vehicle types) average vehicle speeds inside and outside the zone broken down by time of day and weekday vs. weekend; transit ridership data; elasticities (time and price sensitivities, which are pertinent not only to estimating driver response to tolls but also "rebound effects" and mode-shifting among autos, for-hire vehicles and transit); as well as dozens of other area-specific metrics.

The process of adapting the BTA model for use in Washington, DC included specific adjustments to reflect DC's unique transportation system within the three study areas. This entailed gathering, simplifying, and summarizing dozens of data sets from local agencies covering transit use, vehicular traffic, and demographics. A complete list of data inputs incorporated into the BTA model is shown in Figure 49. Trip data from these study areas were built into the BTA model which will allow the project team to analyze the results of different congestion pricing policies and their calibrated approaches to these three different study areas.

Figure 49 BTA Data Inputs

Category	Data Input	Source
Parking	Breakdown of parking between on-street, off-street and reimbursed	MWCOG
	On-street parking rates - weekday	DDOT
	On-street parking rates - weekend	DDOT
	Off-street parking costs - weekday	Parkopedia & Estimated from On-street Parking Rates*
	Off-street parking costs - weekend	Parkopedia & Estimated from On-street Parking Rates*
	Parking reimbursement	MWCOG survey
	Parking tax revenue	ORA
Transit	VRE commuter rail ridership into pricing area	MWCOG
	Metrobus ridership by time of day and weekday vs. weekend	MWCOG
	Metrorail ridership by time of day and weekday vs. weekend	WMATA
	Bus VMT	WMATA
	Bus speeds	WMATA

Category	Data Input	Source
	WMATA budget	WMATA
	Bus operation costs - per vehicle hour and passenger trip	NTD
	Bus operation cost - per passenger trip	NTD
Motor Vehicle Traffic	Weekday volumes and average speeds by time of day, within and outside the proposed congestion zones	DDOT/INRIX
	Weekend volumes and average speeds by time of day, within and outside the proposed congestion zones	DDOT/INRIX
	Truck share of total inbound/outbound/internal traffic	MWCOG
	Vehicle inbound/outbound/internal trips and VMT	CARTO/MWCOG via NN
	Lane miles of roads and streets	DDOT
	Taxi trips by time of day and weekday vs. weekend	DFHV
	TNC trips by time of day and weekday vs. weekend	DFHV
Tolls	Average tolls (without congestion pricing)	TollGoru + CARTO
Population	Population Density	Census
Other	Proportion of Work/Non-Work Trips	TK
	Weighted average distance to downtown in miles	Google API
EVs (Electric Vehicles)	PEV Market share from vehicles on the road	Industry reports
Value of time	Average wage in metro area	BLS
Crashes	Average injuries and fatalities	DDOT + VDOT
Bicycle	Bicycle mode share	Census

*The BTA uses $25 as the assumed costs of all-day off-street parking, also corroborated by numbers in a 2019 Parkopedia[39] resource.

Parking price inputs help to provide a baseline of understanding of DC's parking environment. Baseline parking rates in the study area are a key component of baseline cost to drive into the priced area. They figure into the estimated number of trips that congestion pricing will "price off the road". This input is a key part of the price-elasticity-driven estimates of changes in auto trips into the charging zone, but there is no feedback

loop from baseline parking prices and costs to baseline travel are hardwired into the baseline levels. This prevents the BTA from analyzing a parking pricing congestion scenario, since changing baseline parking costs will not change traffic volumes. Because the BTA cannot test parking pricing as a form of congestion pricing, an on-street parking pricing scenario will be analyzed separately outside of the BTA model and compared to the results of the other congestion pricing scenarios.

[1] https://www.wmata.com/initiatives/ridership-portal/

[2] Urban Mobility Report, Texas A&M Transportation Institute, 2019; https://static.tti.tamu.edu/tti.tamu.edu/documents/mobility-report-2019.pdf

[3] INRX Global Traffic Scorecard, 2019; https://inrix.com/scorecard/

[4] USDOT Congestion Pricing: Safety https://ops.fhwa.dot.gov/congestionpricing/assets/safety.pdf

[5] USDOT Congestion Pricing: Environmental Benefits, https://ops.fhwa.dot.gov/congestionpricing/assets/env_benefits.pdf

[6]Frey, William H., "Six maps that reveal America's expanding racial diversity", The Brookings Institute, September 5, 2019, https://www.brookings.edu/research/americas-racial-diversity-in-six-maps/

[7]2017 American Community Survey, https://www.census.gov/programs-surveys/acs, accessed 2/29/2020.

[8] Ibid

[9] District of Columbia SustainableDC 2.0 Plan, released April 2019

[10] American Community Survey, 2017

[11] Ten counties and five cities include: Prince George's County, MD; Montgomery County, MD; Charles County, MD; Frederick County, MD; Arlington County, VA; Fairfax County, VA; Loudon County, VA; Prince William County, VA; Urbanized areas in Fauquier County, VA; City of Alexandria, VA; City of Fairfax, VA; City of Fall Church, VA; City of Manassas, VA; City of Manassas Park, VA

[12] Prince George's County, Analysis of Impediments to Fair Housing Choice, Revised June 2012; https://www.princegeorgescountymd.gov/DocumentCenter/View/4098/Department-of-Housing-and-Community-Development-Analysis-Impediment-Fair-Housing-PDF?bidId=

[13] Center for Neighborhood Technology: Housing and Transportation Index

[14] Institute on Metropolitan Opportunity, University of Minnesota Law School: American Neighborhood Change in the 21st Century, Low Income Displacement and Concentration

[15] ACS Survey, 2017

[16] Centers for Disease Control, The Healthy Community Design Initiative: Respiratory Health and Air Pollution; https://www.cdc.gov/healthyplaces/healthtopics/airpollution.htm#:~:text=Transportation%2Drelated%20pollutants%20are%20one,birth%20outcomes%2C%20and%20childhood%20cancer.

[17] DC Health Equity Report, February 2019; https://app.box.com/s/yspij8v81cxqyebl7gj3uifjumb7ufsw

[18] CDC Division of Population Health, Epidemiology and Surveillance Branch

[19] DC AV Study Final Report, April 7, 2020; https://lims.dccouncil.us/downloads/LIMS/44545/Introduction/RC23-0172-Introduction.pdf

[20] Office of Planning's State Data Center, https://dcdataviz.dc.gov/node/1371181#1

[21] https://tetcoalitionmbuf.org/

[22] Transit Cooperative Research Program (TCRP) TRB's Report 95: Chapter 3 – Parking Pricing and Fees 2004.p.13-1

[23] E-ZPass Members. https://www.e-zpassiag.com/about-us/members

[24] Mileage-Based User Fee Exploration: 2019 Passenger Vehicle Pilot, The Eastern Transportation Coalition. March 1, 2021. https://tetcoalitionmbuf.org/wp-content/uploads/2021/03/TETC-2019-Passenger-Vehicle-Pilot-Report-1.pdf

[25] DC Vote, "D.C.'s Bid to Impose Commuter Tax Denied – Court Undercuts Home-Rule Effort. https://www.dcvote.org/news/dcs-bid-impose-commuter-tax-denied-court-undercuts-home-rule-effort

[26] Greater Greater Washington, "Myth busting: DC Home Rule prohibits a "commuter tax," but that's not why we don't have congestion pricing". https://ggwash.org/view/67994/myth-busting-dc-home-rule-commuter-tax-congestion-pricing

[27] Washington Post, "Maryland and Virginia drivers owe D.C. more than $370 million in outstanding traffic and parking fines". https://www.washingtonpost.com/local/trafficandcommuting/maryland-and-virginia-drivers-owe-dc-more-than-370-million-in-outstanding-traffic-and-parking-fines/2020/10/04/c11a1df6-030c-11eb-b7ed-141dd88560ea_story.html

[28] Council of the District of Columbia, How a Bill Becomes a Law. https://dccouncil.us/how-a-bill-becomes-a-law/

[29] Python analysis of origin-destination trips within DC region using MWCOG regional model data

[30] ParkDC, 'Penn Quarter/Chinatown Parking Pricing Pilot' Final Report, January 2019

[31] DDOT, Parking Meters; https://ddot.dc.gov/page/parking-meters

[32] "MotorVs" and "Motor Vs Weekends"

[33] Mileage-based schemes are based on VMT

[34] Transit Cooperative Research Program (TCRP) TRB's Transit Cooperative Research Program (TCRP) Report 95: Chapter 13 -- Parking Pricing and Fees 2004. p. 13-4 https://www.trb.org/Publications/Blurbs/155505.aspx

[35] Puget Sound Regional Council Household Survey 2017/2019 Results
[36] Parking Pricing Implementation Guidelines, Victoria Transport Policy Institute
[37] https://www.vice.com/en/article/8x53xb/meet-the-spreadsheet-that-can-solve-nyc-transit-and-the-man-who-made-it
[38] http://www.seattle.gov/Documents/Departments/SDOT/About/SeattleCongestionPricingStudy_SummaryReport_20190520.pdf#page=28
[39] Parkopedia 2019 Parking Index North America